2011

Dynamic Heels

Team 2: Final Report

Team Members:
Nick DiFilippo – Co- Leader and Test Specialist
Kayla Morgan – Co- Leader and Group Facilitator
Tabitha McLellan – Industrial Engineering Specialist
Manuel Müller – Lead Design Engineer

Sponsor:
Candice Cabe

Faculty Advisors:
Professor Bahram Nassersharif
Professor Carl-Ernst Rousseau
Professor Manbir Sodhi

MCE / ISE 402
5/13/2011

Abstract

Many women suffer from Leg Length Inequality, which occurs when one leg is longer than the other. This condition makes it very uncomfortable to wear high-heeled shoes. The goal of this project is to design a pair of high heels that have interchangeable heel heights. The purpose of this is that a woman could wear a 1.5” high heel on one foot and a 2.0” high heel on the other foot allow women with different length legs to feel comfortable when wear high-heeled shoes. During the fall semester the team was able to come up with a variety of design concepts that were then modeled in SolidWorks. A few of the key design concepts were prototyped using the rapid prototyping machine in order to prove that the concept of interchangeable high-heeled shoes is valid. A patent search was performed in order to make sure that none of the design concepts would infringe on any existing patents. Competitive analysis was also performed along with a survey in order to determine the cost that consumers would be willing to pay for interchangeable high-heeled shoes and what styles and materials they would prefer. In depth prototype and manufacturing costs were estimated and a QFD analysis was performed in order to compare the design concepts. During the spring semester the team used the test and redesign process to improve the high heel’s performance. During the entire process the team followed a project plan which gave the group an avenue to make sure that task were being completed in a timely manner and that important deadlines were being met.

Table of Contents

List of Acronyms

DFMA ... Design for Manufacturing and Assembly

DFX ... Design for X

FEA ... Finite Element Analysis

LLI ... Leg Length Inequality

QFD ... Quality Function Deployment

USPTO ... United States Patent and Trademark Office

List of Tables

List of Figures

1 Introduction

Candice Cabe, an Entrepreneur from Boston, came to the University of Rhode Island senior capstone design class looking for assistance with the designing and prototyping of a new shoe concept. The group Dynamic Heels was given this project to work on. This idea will allow women to remove the heel off of their shoe to change the heel height. The height ranges from a 1.5-inch kitten heel to a moderate 3.5-inch heel. The project description that she gave is as follows:

> Seventy percent of Americans suffer from having one leg shorter than the other which requires corrective shoes to avoid health issues. Many of the shoes that can be adjusted for people with different length legs are unattractive and unfashionable. Additionally many women suffer from pain and discomfort when wearing high heel shoes for an extended period of time. The goal of this project is to design high-heeled shoes that would have adjustable heel heights that could be interchanged without the use of tools. The main focus will be to design an interchangeable heel and possibly find an ideal material for a flexible sole.

Candice's previous work on the project includes winning "Startup Weekend", an event focused on entrepreneurs pitching their new product ideas. From there she has established contact with a patent lawyer and a SolidWorks professional to assist her in her product design. She has come to us seeking assistance with the design and innovation of a fastening/locking mechanism that will allow the heels to be removed and replaced with ease.

2 Project Planning

A project plan is important to have during a design project because it shows all of the different team members when different parts of the project are due. It is especially important in an academic setting when the semester is only a few months long (Late January-April) as it is with this capstone project. The project plan can be found in Figure 1.

2.1 Testing

Over winter break, the dynamic heel team was awarded a $1400 grant from the University of Rhode Island in order to assist the funding of the project.In the spring semester, the team started off by redesigning the Twist and Lock design that was created in the fall. Manny was in charge of making all of the changes in SolidWorks throughout the semester.

The main focus of this semester was testing and redesign of the twist and lock heel design. There were various tests that the team wanted to run at the beginning of the semester. These tests included an Accelerated Life Test, a Tensile/Compression Test, a Wear Test, and functionality Test.

The first test that was performed was a function test. This was to ensure that the base and the heel could actually be mounted on the shoe. This test was right at the beginning of the semester and showed that the heel and base were the right size for the shoe.

Nick was in charge of the Accelerated Life Test. This test was to determine the wear that would occur when the heel was twisted into place. This machine had to be designed and fabricated from scratch and took roughly half the semester to get the necessary part, assemble, and make work. In addition, the actual test took around one week to run each time.

Since the parts took so long to receive a lot of the testing that was originally planned just couldn't be done. For example just to get one heel or one test part for the accelerated life test made took 3-4 weeks. It just wasn't possible to get multiple heels made for testing. Originally some of the teams tests called for heels to be tested to failure but this was not possible due to length it took to get heels made. At the beginning of the semester the possibility of outsourcing the manufacturing toa outside company was explored but quickly abandoned due to cost.

Tab, Kayla, and Nick were in charge of designing the fixtures to hold the heel in the tension/compression tests. These tests were also performed using computer simulations that were done by Manny.

One additional test that the team wanted to run was a "Wear Test" would be to put these heels on a shoe and have Kayla and Tab walk around for a day. Since the only heels that could be made with an reliability had to be rapid prototyped the strength of the heels was not very good this test had to be abandoned.

The only way to get around the manufacturing problem was to run computer simulations on the tests that needed to be accomplished. For these tests Manny was in charge of running the simulations in Abaqus and SolidWorks.

2.2 Meetings

Meetings with the team sponsor Candicewere scarce this semester because she was moving forward with a different design for the detachable heel. A few meetings did take place that involved phone conferences with the professors, the team, and Candice.

During the semester the team usually tried to meet at least one time a week. Meetings were scheduled on a Wednesday during the time capstone would be. If there was a capstone lecture group meetings would occur directly before or immediately after the lecture. Kayla and Tab were in charge of filling out and submitting the weekly progress reports that were due late in the afternoon on Wednesday. Kayla was also in charge of updating the project plan and posting it to Sakai.

2.3 Events

The two big events that the tam had to prepare for were the mid semester presentation and the design showcase. All the members of the team worked on the PowerPoint for the mid semester presentation. For the showcase, Kayla was the team member in charge of making the poster and the pamphlets that would be handed out during the showcase.

3 Cost Analysis

3.1 Sources of Funding

The source of funding for this project was an Undergraduate Research Grant from the University of Rhode Island's Division of Research. A proposal for the undergraduate research grant submitted on December 1, 2010 and was received in early February 2011. The grant was for scholarly, creative, and artistic projects and the team was awarded $1400. The money was used to buy supplies for prototyping and test, and the expenses are shown in the figure below.

Supplier	Description	Cost
McMaster-Carr	Parts to Make Accelerated Life Fixture	$164.63
Naturalizer, Inc.	High Heels (Four Pairs)	$241.47
McMaster-Carr	Parts to Make Accelerated Life Fixture	$77.54
Bosworth	Parts to Make Accelerated Life Fixture	$125.90
Naturalizer, Inc.	Returned Two Pairs of Shoes	-$98.99
Naturalizer, Inc.	High Heels (Two Pairs)	$142.48
	Sub-Total Spent	$653.03

Table 1: Table listing how funds were spent

As the above table shows the funds were used to buy high heels shoes for the function tests and parts to make the accelerated life fixture test. The high heels were bought from Naturalizer, Inc. because the sponsor specified that these heels had a flexible sole and that they would be used to manufacture the shoe. The parts used to make the accelerated life fixture were raw metals, pumps, pistons, and electronics.

3.2 Work Hours Spent on the Project

Many hours were spent working on this project, not only by the group members but also by the advisors and consultants. Each group member spent roughly six hours a week on this project. This time was spent meeting with the group, the advisors and the sponsor, as well as performing individual project tasks. The group worked on this project for roughly twenty-four weeks throughout the fall and spring semester, therefore each team member has spent roughly 144 hours on this project totaling 576 hours of work as a team. Junior engineers typically get paid between $20-$50 per hour which means that the team's work hours would have had a cost between $11,520 and $28,800. The advisors spent roughly thirty-five hours each on our project. This time includes team meetings, discussions with the sponsors, reviewing weekly status reports, and help writing the proposal. Senior engineers can get paid anywhere between $100 and $500 per hour which would cost between $3,500 and $17,500 for each professor's time. As a group we had met with our consultant Professor Claire Lacoste-Kapstein for two one-hour meetings and corresponded questions via email. She also spent additional time with the group by coming to the Preliminary Design Review presentation. Although the group spent time together working on certain tasks as a group, each group member also had individual task that they had to accomplish. Nick spent most of the semester designed, producing, and running the accelerated life cycle test. Tabitha and Kayla spend most of the semester doing technical administrative tasks such as creating reports, powerpoints, contacting machine shops, placing orders, and assisting with testing. Manny spend most of the semester improving the twist and lock design in SolidWorks.

3.3 Prototype Analysis

The prototype costs were relatively small, they consisted of rapid prototyped heels and a variety of pins and spring loaded ball plungers. The rapid prototype costs are based on the size of the piece that is being produces, roughly $25.00 per cubic inch. The rapid prototyped heels that were produced for this project and their costs are shown in the table below.

	Quantity	Unit Costs	Total Cost
Axial Heel	1	$43.55	$43.55
Slide Heel	1	$28.65	$28.65
Twist & Lock	4	$56.40	$225.60
Push Button	1	$63.20	$63.20
		Total:	$361.00

Table 2: Table of the heel designs that were rapid prototyped and their costs

3.4 Mass Production Cost Analysis

The team was fortunate to have an industry sponsor that was able to assist in the mass production cost analysis. The industry sponsor was Amanda Bligh who is an implementation engineer at the company aPriori. The heels would be injection molded and a single mold would hold all heels and the heel base that way one whole set would be made at one time. The mold would cost between $20,000 and $30,000. The raw material would cost approximately $0.60 for the heel base and approximately $2.50 per heel. Allowing an amortization period of 10,000 pairs, each heel set would cost approximately $31.40 to $33.40. The sponsor has stated that she would like to sell each pair of high heels for approximately $150.00. To allow for at least a 50% markup the high heel shoes would need to be produced for at most $75.00 per pair. With each heel set costing between $31.40 and $33.40 per pair it would allow approximately $40.00 to make the shoe body, which is a reasonable cost for the body of the shoe.

4 Quality Function Deployment

The How-How part of the house of quality shows the following relationships. As the weight of the shoe increases the ability of the shoe to be able to hold a weight of a person will go up. The weight of the shoe can increase because of increased of a bigger heel or more parts to keep the heel secured to the foot. Also as the weight of the shoe increase this may negatively affect the heel design. This means the fashion part of the heel will have to be compromised. This part of the house of quality also shows that as the force to remove a heel goes up the heel lifespan is increased. This is the case because the heel will not be removed accidently and in a wrong manner which could put the heel under stresses that it was not designed to withstand. Also the heel lifespan can also be thought of how long a person will wear the heel. If the heel is releasing by itself the person will not want to wear that heel.

As the heel is more able to hold the weight of a person, the heel lifespan will decrease because there will be extra weight and therefore extra stresses on the heel. Also as the heel is able to hold the weight of the person the engineering design of the shoe would increase because the design would allow for more weight to be held. Finally as the heel lifespan increases the design of the heel increase. This is the case for the same reason the design increases when the heel has to withstand the weight of a person. This is shown in Figure 2.

5 Patent Searches

A patent search is an incredibly important step that anyone must take at the beginning of a design project. This search provides information about progress that has already been made about the product that is trying to be designed. It can show ideas that have been thought of but maybe not pursued or ideas and designs that work from a competitor. It is possible to use these existing ideas so a design isn't starting from scratch but is different enough so it doesn't violate the existing patent.

For interchangeable high heels, a patent search was conducted by all of the team members. Initially primary terms that were searched were high heels and shoes. At this point it was clear that the search had to be specified down because all of the patents that came up dealt with the actual shape of the high heel shoe. A term of removable/adjustable/variable/detachable/interchangeable was added to narrow down the search. Using this method it is easy to determine the class number that is used on the patents. The class number that all of our patents used was 36. Class 36 is Boots, Shoes, and Leggings. This class is what all of the patents regarding shoes will fall into. The USPTO office gives the following definition.

> "This class is intended to receive foot coverings which are generally provided with reinforced tread surfaces. This class also receives leg protecting devices generally designated as leggings or gaiters. This class also receives antislip devices and wear members to be applied to boots and shoes. This class also receives shoes which are specifically designed to be placed on the feet of deceased persons."

In addition to just having a class, there are multiple subclasses that apply to the problem of interchangeable high heels. More specifically patents with the subclasses 15, 36, 42, and 100 were looked at. The USPTO gives the following definition for each of these subclasses.

Subclass 15: Detachable Soles

> "This subclass is indented under **subclass 12**. Sole attaching means in which the wearsole is provided with means whereby it may be readily attached to, or detached from the remaining shoe structure."

Subclass 36: Detachable

> "This subclass is indented under subclass 35. Products in which the cushion heel, or some part of it, is so connected to the shoe or to some other part of the cushioned heel that it may be readily removed therefrom, as for adjustment or replacement."

Subclass 42: Detachable (under subclass 34)

> "This subclass is indented under subclass 34. Products in which means are provided to permit the ready removal of the heel or a portion thereof from the shoe, as for replacement."

Some of the more pertinent patents that relate the design of a variable high heel will be explained below:

US Patent Number 5,079,857 describes a detachable heel with a screw mechanism. This patent has the threaded portion of the screw extruding down from the heel. On the inner portion of the foot there is a pin in a slot that is used to lock the heel in place. The detachable part of the heel would be able to screw onto the main part of the shoe

US Patent Number 5,456,026- This patent has a lip on the main part of the heel. The interchangeable part of the heel is allowed to slide over the lip and when it is pushed a certain amount it will snap into place. There is a part on this lip that sticks past the edge of the heel so it can be lifted up when it becomes time to change the heel. Lifting this part up acts as a release mechanism

US Patent Number 6,021,586- This patent describes a heel that is pushed up into another heel . A spring mechanism is connected to this heel and when this spring is pushed up past a hole on the outer shell of the outside heel it will pop out and lock into place. There are different holes at different heights on the outside shell that correspond to different heel heights that might be desired.

US Patent Number 7,059,068- This patent describes a flexible sole that needs to be in place in order to be able to change the angle. The heels is attached by putting twos different heels together. The drawings of this patent don't show any type of locking mechanism and instead look like it relies on the weight of the person to hold the heels on the shoe. This wouldn't be a problem if the heels were taped because the tolerances at the end of the part could be much smaller and the heels would essentially become "jammed" into each other.

US Patent Number 7,185,448- This patent explores has different heel sizes with a blade the comes out from the front side. This blade can be inserted into the main part of the high heel. The main part of the shoe can be lifted up in order to change the heel out. To insert a new heel, you would first press a button that is connected to a spring. This spring pushes on a latch and unlocks the original heel. Then you would lift up the part of the shoe that your heel would be on and insert the new interchangeable heel. The lip of the heel will into a hollow component that would be under the bridge of your foot. The part of the heel that was lifted up is now pushed back down and fits into a hole on the interchangeable part. This part will push past the latch that will lock the heel in place.

US Patent Number 7,578,075- One of the claims of this patent is a heel shape that slides in from the front of the foot. When the heel is pushed in as far is it can go in the groove that is made to fit it, it will lock via a spring mechanism that is under the arch of the foot.

US Patent Number 11,667,574- This patent changes between two heights. One of the heights is when the heel is in the down position and the other height is when the heel is folded forward. To change between the two different heights you push the heel towards the front of the foot. In this design the heel is not removable even though the height is variable.

For this project the patent search has been a source of inspiration of different ways to connect the shoe to the heel. These patents have also been used while trying to think of different ways to lock the heel in place while trying to keep the design as simple as possible. The more complicated the designs with small and complicated parts, the more expensive the heel will be to manufacture. All referenced patents except patent Number 11,667,574 can be found in the appendix.

6 Evaluation of the Competition

The competition for this design includes all current footwear companies, including those with and without interchangeable heels. The companies that the Dynamic Heels group will be competing with include high-end shoe designers such as Nine West, Jessica Simpson, Steve Madden, etc. These companies focus on fashion, which will be the Dynamic Heels group main concern along with safety and reliability. These and other companies all have several different styles of shoe, all in varying heel heights. If a consumer went with one of these companies, they would likely purchase at least two pairs of shoes, including a high heel for dressing up and a lower heel for comfort and casual occasions. One particular new product that may answer some of the problems women face with high heel wearing is the new Dr. Scholl's Fast flats, which is shown below.

Figure 1: Dr.Scholls Fast Flats

These are portable flats that come in a wristlet making comfortable footwear portable. These are a product that would require consumers to purchase an additional new pair of shoes to change into, as opposed to our product only requiring one shoe purchase. It is clear that the Dynamic Heels group product has a competitive advantage to traditional shoes, giving portability and convenience to change the shoe.

There is one product currently on the market that has similar features to the proposed product: CAMiLEON Heels. This company has designed a shoe that can switch between two heel heights: 3.25" and 1.5". The Dynamic Heels group product has several advantages over this design. One such advantage is that the Dynamic Heels group shoes will change to five different heights, allowing more flexibility for the consumer. In addition, Dynamic Heels group product design is more aesthetically pleasing, not having an extra heel piece showing while being worn in the lower heel height position. CAMiLEON Heels, shown in the figure below, are very expensive, costing a consumer anywhere from $150.00 to $200.00+. The Dynamic Heels product will be less expensive which will cater to consumers in many demographics.

Figure 2: Photograph of the CAMiLEON Heels

7 Design Specifications

There was a list of customer specifications that we received from Candice that the team turned into engineering requirements which were used to design the heel. The first customer specification was that Candice wanted multiple heel heights. This was turned into a engineering requirement by decided that there would be 5 heel heights varying from 1.5” to 3.5” with a variance of half an inch. Another customer specification was that the design should be simple.

Candice wanted it to be simple for the consumer to use as well as simple to manufacture. This was made into an engineering requirement by confining the design to two pieces and only 2 steps to attach the heel. Candice let us know that she wanted to sell her heels as high-end high heels in a price range of roughly $150.00 per pair. This customer specification means that this team need to leave room for at least a 50% profit margin, therefore the heels need to be manufactured for under $75.00 per pair. Assuming that the shoe part will cost less than $40.00 per pair, this team needs to be able to manufacture the heels for less than $35.00 per pair. Candice specified that she does not want the shoe to show wear, which was turned into an engineering requirement by saying that the design must be able to withstand 14,600 cycles without showing significant wear. The team chose 14,600 cycles because that would simulate a woman changing the heels 4 times a day for 10 years. The next customer specification was that the heel must not absorb water, which means that the heel must be made of a material that doesn’t not absorb water. Candice also specified that she does not want the heel to bend or break under the weight of a woman. This was turned into a design specification with the help of a few ergonomic books. Approximately six times a woman’s weight is pushed down into the ground when she stands up, who our heels need to be able to withstand that amount of force. From a weight chart our team was able to find that a women in the 95th percentile weights approximately 235 pounds, therefore the heel needs to be able to withstand 1,410 pounds in compression. Candice stated that there needs to be a locking mechanism, therefore the design must be able to lock in place and not come undone until the consumer wants it to come undone. The last customer specification is that the heel must be able to be attached without the use of tools. The engineering requirement for this was found with the use of a few ergonomic books and is that the heel must be able to twist on with less than 50 in-oz (0.353 N-m) of torque. A summary of the design specifications are shown in the table below.

Table 3: Design Specifications

Customer Specifications	Engineering Requirements
Multiple heel heights	5 heel heights (1.5”, 2.0”, 2.5”, 3.0”, 3.5”)
Simple	Confined to 2 pieces and only 2 steps
High-end cost	Shoe must be able to be manufactured for under $75.00 to leave room for a 50% profit margin
No Wear	Design must be able to withstand 14,000 cycles without significant wear to where the heel won’t work as designed
No Absorption	The heel material will not absorb water
Compression	Design must be able to withstand 1,410 pounds. (6 times the weight when stand up – 95th percentile womens weight which is 235 pounds)
Locking Mechanism	Heel must lock in place
No tools	Must be able to attach by hand with less than 50 in-oz of torque. (0.353 N-m)

8 Conceptual Design

At the beginning of a project, concept generation is important to try to come up with a solution to the problem at hand. By being as creative as possible, one is able to come up with solutions that are not obvious at first look. However, a list of pros and cons should be provided with each of the designs to try to determine if the designs that were thought of are reasonable. The best designs are usually simple designs without too many complicated parts. The designs below were generated by each member in the group and have been filtered to include concepts about how to attach the heel and exclude the concepts ideas that were generated by multiple people.

8.1 Screw Design Concepts

1. This design has a screw on the heel that would be twisted onto the shoe. This design is feasible and that it would be able to hold up to the stresses that heels are put under, but the screw threads would have to be perfect because the heel is not symmetrical. This design is a possibility but is not the best design. The design is shown in the figure

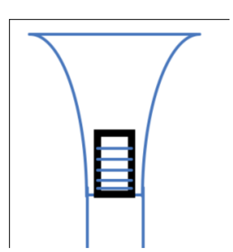


Figure 3: Drawing of Screw Concept 1

below.

2. This design concept has little heels that each have screws on them and if you wanted higher heels you would just screw on another little heel piece. This idea may not be feasible because the screw threads would be important and would have to screw to a certain part because the heels are symmetrical. The little heel pieces may not be long enough to allow a screw to be screwed into it. This design is shown in the figure below.

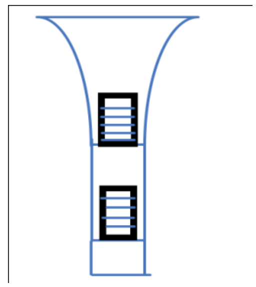


Figure 4: Drawing of Screw Design 2

3. This design is for a screw that has the screw on the outside. The heel would have a threaded screw on its inside and the heel base would have a threaded part of the screw on the outside. The drawback of this design is that a symmetrical heel is still needed. If the heel is not tightened all the way then the heel might still not be stable or safe. This design is shown in the figure below.

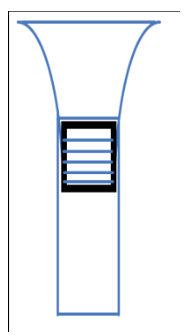


Figure 5: Drawing of Screw Design 3

8.2 Slide Design Concepts

1. This design concept is that there would be a heel that would slide into the shoe, and then the person would have to slide a pin into the shoe that would hold the heel into the shoe. One drawback is that this design has many parts. There is a good chance that the little pin part would get lost, and then the shoe wouldn't work. This design is shown in the figure below.

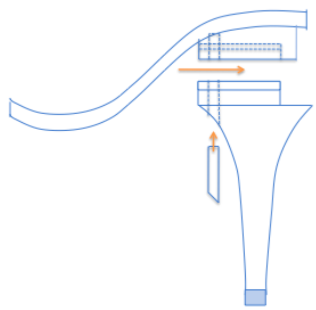


Figure 6: Drawing of Slide Design 1

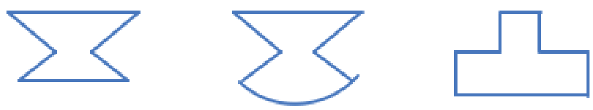


Figure 7: Drawing of Slide Design 1 Slide Pin Ideas

2. This design concept has a heel that would be put up to the sole of the shoe and slid back and snapped into place. This is a feasible idea as long as sufficient analysis is done to make sure that the edges would be strong enough and the shoe wouldn't break. This design is shown in the figure below.

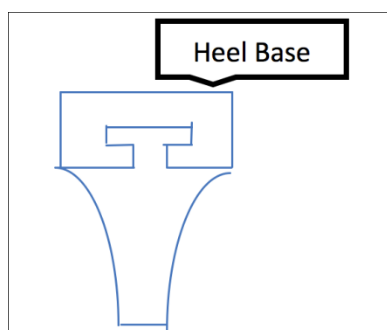


Figure 8: Drawing of Slide Design 2

3. This design concept has the heel having a shape like an outlet and it would plug into the shoe. If the tolerances were very high or if the connection was tapered this idea could work. Also there is a change that the heel would break at the outlet part. This design is shown in the figure below.

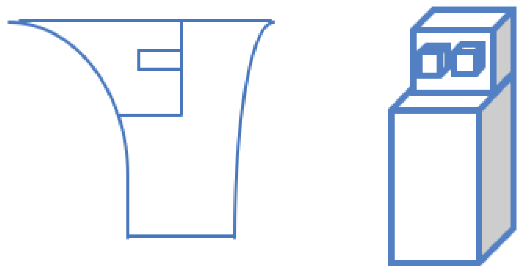


Figure 9: Drawing of Slide Design 3

8.3 Axial Design Concepts

1. This is a design for a slide on from the bottom. The cross section area of the part that pushes into the shoe can be an "L" shape, a 'C' shape, a "T' shape, a triangle, a square, or a circle. The different geometries have a downside that they could be inserted in a wrong orientation but are stronger. The letter geometries can only be inserted one way but they might be weaker. This design is shown in the figure below.

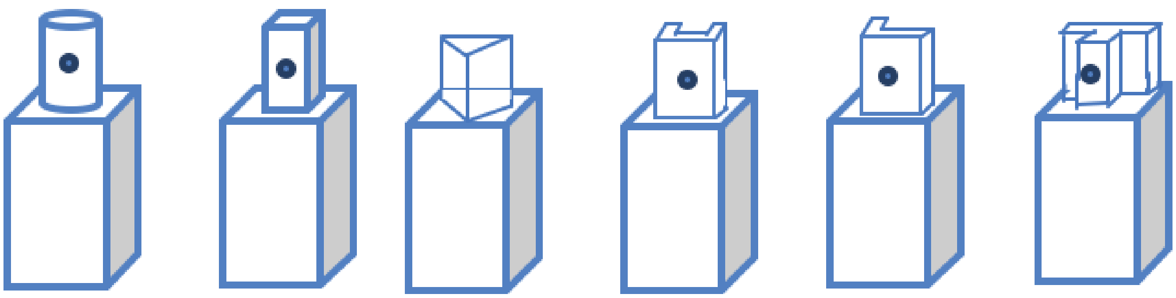


Figure 10: Drawing of Axial Design 1

2. This is an O-Ring that is on the foot part. The heel would push up into the base of the heel and the friction from the O-Ring would be able to keep the heel on the base. The O-Ring design could also be on the heel attachment. This is a better design because if the heel breaks or if the O-ring wears out then the shoe will not be affected and a new heel can just be purchased. The O-Ring will create friction that will allow the heel to stay in. This design is shown in the figure below.

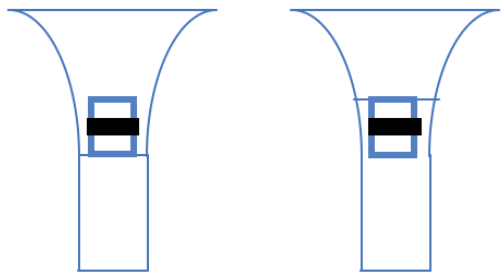


Figure 11: Drawing of Axial Design 2

8.4 Snap In Design Concepts

1. This design concept is a ball that would pop into the shoe. A drawback to this design is that the ball could break off easily and the ball joint may not be able to provide the necessary support and hold up under the stresses that high heels are put under. This design is shown in the figure below.

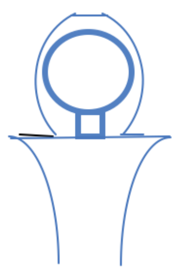


Figure 12: Drawing of Snap in Design 1

2. The heel would push up and push against a spring. The spring would provide resistance so when it is set the heel would be in good. This might not be a strong idea because spring might be compressed more with every step that is taken. This could be avoided if the spring was compressed as much as it could when the heel was fully pushed in. However some drawbacks are that the spring could compress when walking and the spring could break which would make the complete shoe ineffective. This figure is shown in the figure below.

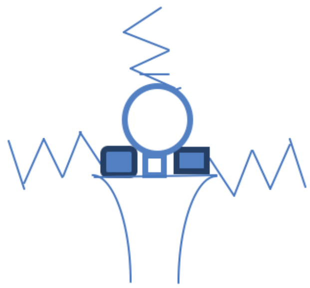


Figure 13: Drawing of Snap Fit Design 2

3. This design is a snap fit that occurs on the outside of the heel. This heel would be easy to put on and to remove however it may be able to break easy because it is made of plastic. The snaps aren't hidden so it could make it aesthetically unappealing. This design is shown in the figure below.

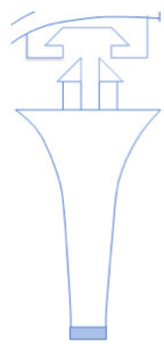


Figure 14: Drawing of Snap Fit Design 3

4. This design idea is for a snap fit that would attach the heel to the base of the shoe. The heel would attach to the base like a battery cover on a calculator and that is how the heel would be released. This concept would be aesthetically pleasing because the snap fit would not be able to be seen unless the shoe was flipped over. This design is shown in the figure below.

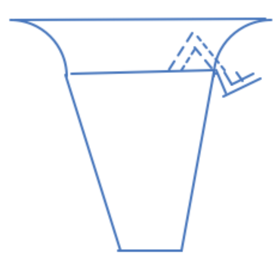


Figure 15: Drawing of Snap Fit Design 4

8.5 Magnetic Design Concepts

1. This design concept could be applied to different shoe designs. This idea is that there would be a magnet in the shoe that would hold the heel to the shoe. This concept could be applied to heels that slide in or snap in or any other different design concept. The magnet is a feasible idea for hold except for that the magnet may lose its strength over time. This design is shown in the figure below.

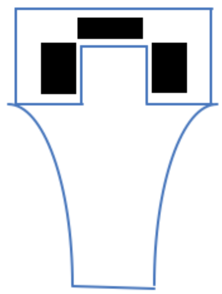


Figure 16: Drawing of Magnetic Design 1

8.6 Twist and Lock Design Concepts

1. This design is for a twist and snap method. When the grooves on the heels are aligned with the inserts, the heel can be rotated 90 ^{o} and lock into place. The pros of this design are that they design could only rotate one way so it would be obvious if the heel was inserted wrong. However this may be a difficult part to build because of the internal features which could drive up the machining costs. This design concept is shown in the figure below.

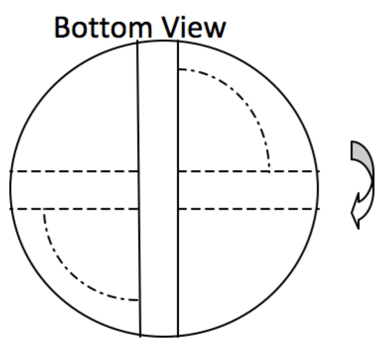


Figure 17: Drawing of Twist and Lock Design Concepts

2. This design focuses with a heel that is inserted from inside the shoe. The heel would be inserted from the inside and twisted to lock it in place similar to the twist and lock idea. Having a insert on the inside of the shoe might not be great because of the pressure that put on the foot if the heel was not flush. There would also be pressure because of the steel rod that runs along the heel. This design in shown in the figure below.

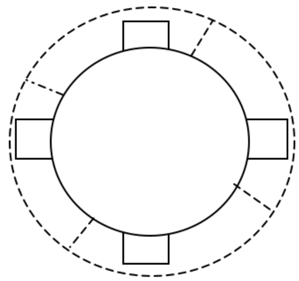


Figure 18: Drawing of the Twist and Lock Design 2

8.7 Conclusion of Concepts

The group has three major typed of designs that they are still trying to pursue. These designs are a heel that pushes up from the bottom of the heel, a heel that slides on, and a heel that twists and locks. These are the three major designs although the smaller details of each type are variable. For example a heel that pushes up from the bottom and locks in could have a spring loaded ball plunger on either the heel insert or the part the heel pushes into. The group has been classifying these as two different concepts while in reality they are variations of these three major types of designs.

9 Design for X

9.1 Design for Aesthetics

There are three main aspects that these heels were designed for: aesthetics, safety, and reliability. Aesthetics is first and foremost the most important aspect of the heel design. Women wear high heels because they look good. The results from the performed survey showed that “shoe attractiveness” was the most important aspect to a woman when she is going to buy a pair of high heels. If the heel is not aesthetically appealing then no one will buy the shoes, which is why this is the most important aspect of the heel. It doesn’t matter if the shoe is safe, reliable, and cost effective, but if the shoe is not visually appealing then no one will buy it. The Dynamic Heels group designed for aesthetics by modeling the heels off of other high heels that were felt to be visually appealing. The members of the Dynamic Heels group also had to learn some new SolidWorks features in order to create the surfaces necessary to make a visually appealing high heel. Some of the design rules that were used during the conceptualization of the design were to use no sharp edges because they would not be aesthetically appealing on a high heel and they may be sharp enough to hurt someone.

9.2 Design for Safety

The second thing that the heel was designed for was safety. If someone buys this shoe because they like the style of if then the next most important thing would be to make sure they are safe when they are wearing it. In order to make this shoe safe there needs to be a locking mechanism that locks the heel in place while the shoe is being worn. If the heel accidentally fell out while a woman was walking then she could break her ankle. There are several locking mechanisms that our group came up with to lock the heel in place including pins, snap locks, and buttons. The locking mechanism will be what makes this shoe safe to wear.

The team spent most of the spring semester focusing on designing for safety. They did this by coming up with new ways to lock the heel in place in order to ensure that the heel would not fall off when someone was wearing it. There are small nodes that on the heel that act as a primary locking mechanism, but during testing it was determined that those locking nodes were not strong enough to hold the heel in all circumstances. In order to fix that situation the team made a secondary locking mechanism, which was a force that would push down on the heel and hold it in place. The team had two types of secondary locking mechanisms, one was a compression spring and the other was a piece of rubber. Both acted in the same way by pushing down on the heel and holding it in place.

Another factor that was taken into consideration when the team designed for safety was the force that it took to twist the heel into place. Ergonomic standards state that twisting forces by hand should be less than 50 in-oz. The team checked the heel to make sure that it's torque was less than 50 in-oz by using a torque wrench.

9.3 Design for Reliability

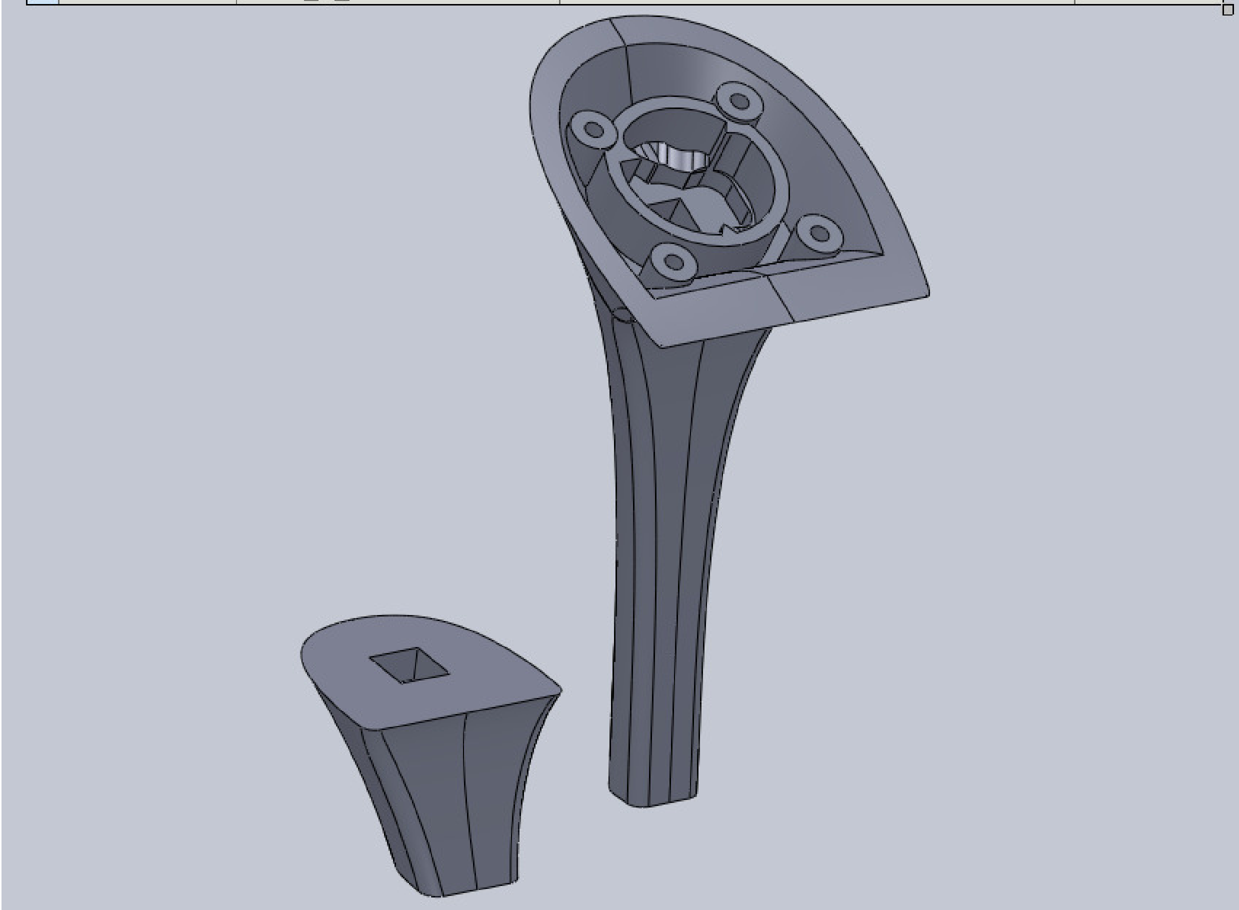
Lastly, the heels were designed for reliability. When someone buys a pair of shoes they expect the shoes to last a long time and hold up under everyday wear and tear. The variable heels are being design to be a high-end pair of shoes, which means that they will be sold at a reasonable high price. The heel was designed to be made from nylon which a strong yet durable material which is ideal for this situation. Other pros to using nylon is that it is relatively light weight and it is water proof, which are two qualities that are necessary for this product. Another way that the team designed for reliability was to perform an accelerated life cycle test. The accelerated life cycle test simulated 10 years of wear on the locking mechanism in the shoe, and the results showed that the nodes held up very well. This proves that the reliability of the shoe is relatively good. The accelerated life cycle test is discussed in detail in 13.8.

10 Detailed Product Design

10.1 Final Product Design

10.1.1 Bill of Materials

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Heel_Base FINAL		1
2	Heel_35_FINAL		1
3	Heel_1_FINAL		1



10.1.2 Description

The high heel shoe design that the team ended up designing to completion was the Twist&Lock connected design. Prototypes of two of the heights were produced using the rapid prototyping machine. The 3.5inch heel was also machined out of nylon at an earlier stage of the design. All connectors were made out of nylon, which is the final material chosen for this part. A prototype of the heel base for testing was made out of aluminum, but turned out to be too hard for this application. All parts, except for the nylon connector, are to be made out of delrin, which was chosen after extensive wear tests and compression tests. Delrin is harder than nylon, preventing the nylon from digging through it during connection cycles as well as prevents damage to the heel from minor bumps and scratches that heels can get with daily use. Delrin is also soft enough that the nylon does not scrape off as it did when it went through the connection cycles with aluminum.

Figure 19: Final Product Design

The main connection works because of the connection design shown on the left. This connector is screwed into the differing heel heights during the final assembly of the heel in manufacturing. When the heel wants to be attached to the heel base, which is permanently attached to the shoe, the three connector nodes need to be lined up with the corresponding spaces in the heel base and inserted. The heel is then rotated in the only direction possible, locking it in place, using forces that come from the elastic deformation of protrusions attached to the bottom of each of the three connector nodes. Within the heel base, there are grooves that will embraces the protrusions to a certain degree, but continue to allow for elastic deformation, which will prevent the heel from wiggling and shaking. During the design process, the radius of the protrusions as well as the transverse width, needed to be increased to prevent the protrusion from shearing off in the very first connection cycle. This was a problem in the design explained in the next paragraph.

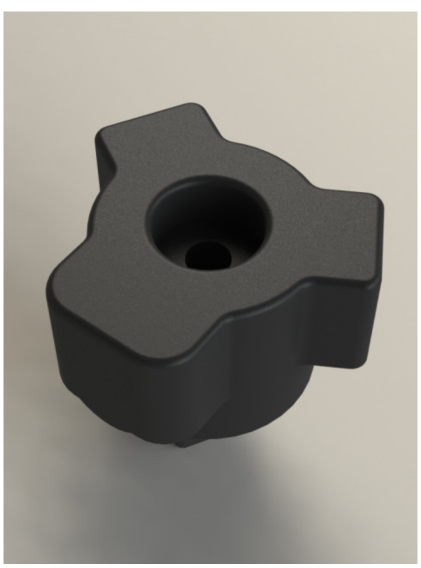


Figure 20: Connector Node

To make the design fool-proof (of poke-yoke design), one of the three connector nodes as well as its corresponding space in the heel base, is significantly larger than the other two. This prevents the user from inserting the heel into the heel base at and incorrect angle, making the shoe far more difficult to use. In this drawing of an older design pictured on the next page, four nodes of the same size and shape were used. The obvious poke-yoke problem is fairly easy to understand in this image. The other issue is the strength of the nodes. Using three nodes instead of the four pictured here, significantly increased the strength of the entire connection area.

In an even older design the heel base was completely filled in with material. This material was removed to decrease the weight of the product as well as decrease the cooling time of the part when it is injection molded. Any decrease in this cooling time significantly decreases the cost of manufacturing. In this older design to the right, the connector was still part of the same mold of the heel, which actually also increases the cost significantly. Separating the connector from the heel allows for easy replacement of the connector as well as allows for a different material to be used for both parts during manufacturing. When being injection molded, the two parts being separated decreases the cost because the parts can cool much faster, as they are no longer one large thick part.

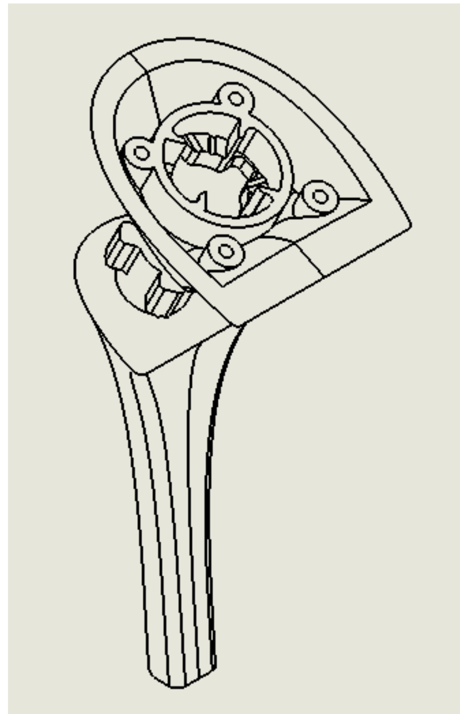


Figure 21: Drawing of Final Design

Most of the design work was done using SolidWorks for modeling and printing. The main shape of the heel and heel base was estimated from an existing heel shape and used to model a master heel shape from which all designs were shaped and cut. Due to the complex geometry of the heel, traditional shape extrusions were not possible in the initial building of the design. Surfaces needed to be extended across splines and knit together. After an enclosed shape was formed, the excess surfaces were trimmed and the shape was turned into a solid body onto which the connection design could be then added.

This connection design proved to be the best design for many reasons. First of all, it was the simples of them all, using only three parts and five screws. The connection forces are small enough for a person to easily overcome in a connection cycle, yet strong enough to support the weight of a heavy person. This design also accounts for poke-yoke situations, where someone might accidentally use the part incorrectly. The part is also fairly cheap to manufacture and requires no extra parts to assemble. There are no parts that can easily be lost. The heel also has a shape that is compatible to many shoe styles already on the market, as well as the specific brand Naturalizer, which has the flexible sole required for a varying heel height.

11 Engineering Analysis

A finite element analysis is usually the best way to analyze the integrity of the design of a new part or product. In this case, a finite element analysis was done on all of the parts of the high heel assembly. Finite element analyses were also done on older models and ideas but are no longer relevant or interesting for this report. To acquire more precise results the analysis of the 3.5inch heel was done with the connector attached and in both the SolidWorks and Abaqus FEA programs.

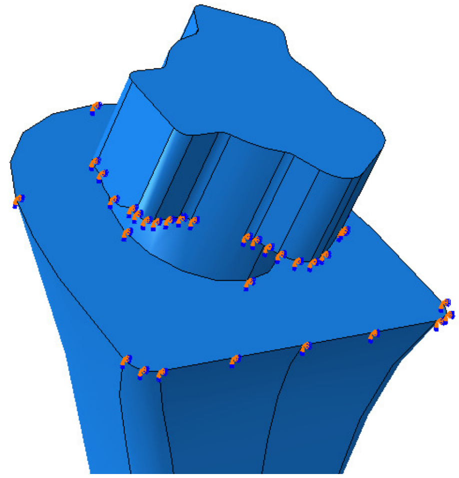


Figure 22: FEA 1

All parts were subjected to a simulated 300 lb force coming form the bottom surface and were fixed at the top in such way to mimic the actual part connections. In the image to the right, the surfaces directly under the three nodes of the connector were completely fixed as they would be completely wedged in when fully attached to the heel. All six degrees of freedom are fixed at every node of every element in the mesh of those surfaces. The large surface directly under the nodes has a 'roller' type of fixture. Only one degree of freedom is fixed on a 'roller' fixture, preventing the part from moving in the normal direction from that surface.

In the next image, the results of the Abaqus FEA finite element analysis are displayed in a contour plot showing the varying von Mises stress and stress concentration areas. The maximum von Mises stress can be seen as 3.04e7 N/m^2 just around the middle part of the front surface of the heel. Because the yield strength of Delrin is approximately 6.3e7 N/m^2, the factor of safety is over 2, ensuring that this design is safe for this situation. These results can then be compared to the next contour plot showing the same analysis but using SolidWorks. In that analysis the meshing algorithm was a little different as well as the mesh size, making the results a little different from the previous. The maximum von Mises stress in from this analysis is 3.6e7 N/m^2. The factor of safety in this one is also well above 1, which means that it is still safe for daily use. This one analysis is of course only of one situation, which means that many other loads and pressures need to be applied to the simulation to meet all safety standards.

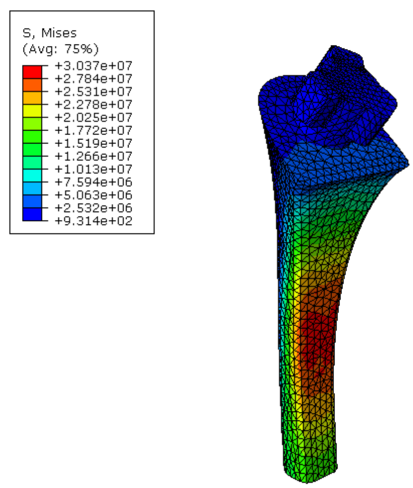


Figure 23: FEA 2

The next finite element analysis was done on the one inch heel without the connector attached. This part is to be made out of Delrin and will have the connector, which is made out of nylon, attached in the rectangular part at the top. In this case a 300 pound force was applied normal to the bottom surface of the heel. The results, with a von Mises much lower than before, prove that this heel is even safer from failure than the high heel.

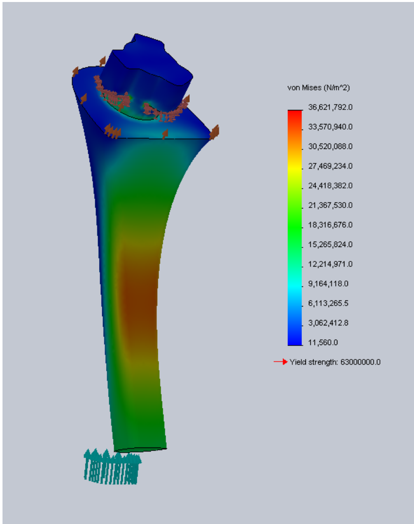


Figure 26: FEA 3

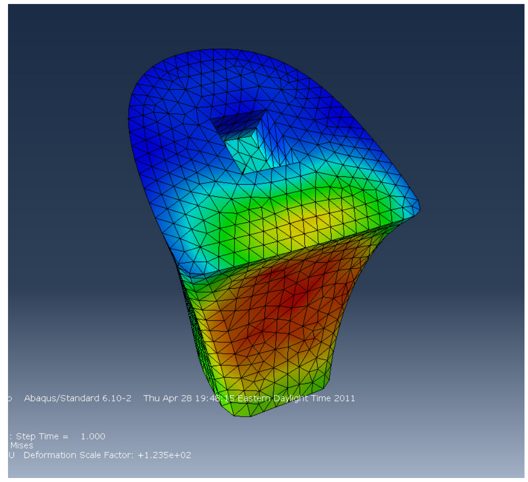


Figure 25: FEA 4

The heel base, onto which the heels will ultimately be attached, also needs to be able to carry the load of one person (at least 300 pounds) stepping on it. This force was distributed again across the bottom surface, where the heel would transfer all of the forces into this heel base. The top part was completely fixed, as it would be to a foot. The main stress concentrations could be found in obvious locations with sharp angles and corners. Fortunately, none of the stresses came close to the yield strength of Delrin or even nylon, which will keep the entire assembly functioning properly, even in the case of an incredibly heavy person (400+lbs) using the shoe. A finite element analysis was also done on the connection between the connector and the heel base. Unfortunately, the file has too many errors and therefore does not have reliable results to be displayed in this report.

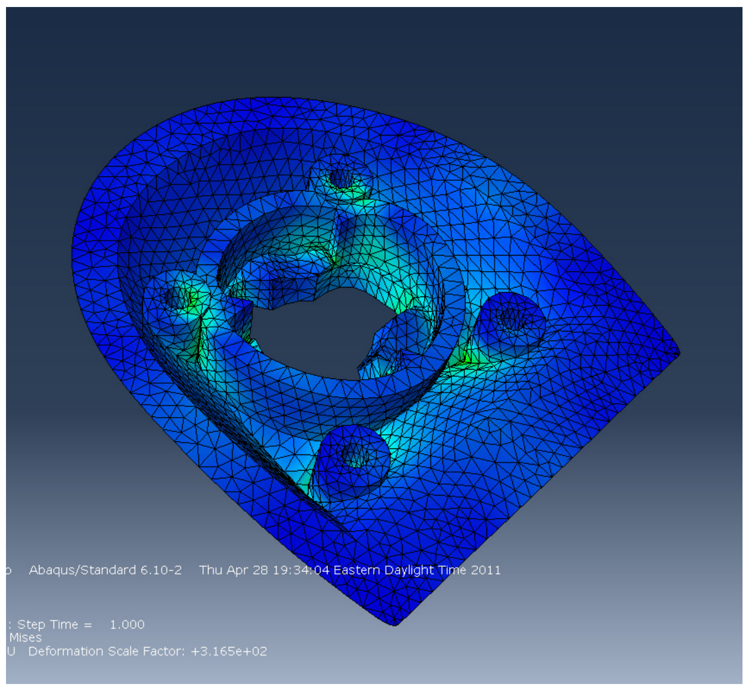


Figure 24: FEA 5

12 Manufacturability

In order to manufacture the prototype, we will utilize injection molding. Machining our product is not an option because of the complicated geometries in the design of the locking mechanism. We had many issues getting our prototypes machined for this reason. Unfortunately, there is no way to simply program a CNC to do the work to a piece of nylon, many of the machining must be done by hand. For this reason, we decided that injection molding is the best way to go. This process is shown below in figure Figure 27: Injection Molding Diagram on a different type of piece. We would have one mold for all seven pieces, including five heel heights, the connector node, and the base to the heel. We have decided to keep our design in three pieces (heel, base, and connector node) in order to cut down the cost of injection molding. The longer a piece takes to cool (because of variation in thickness of the plastic), the more expensive it becomes to manufacture with this method. For this reason, we have decided to veer away from our original two-piece design.

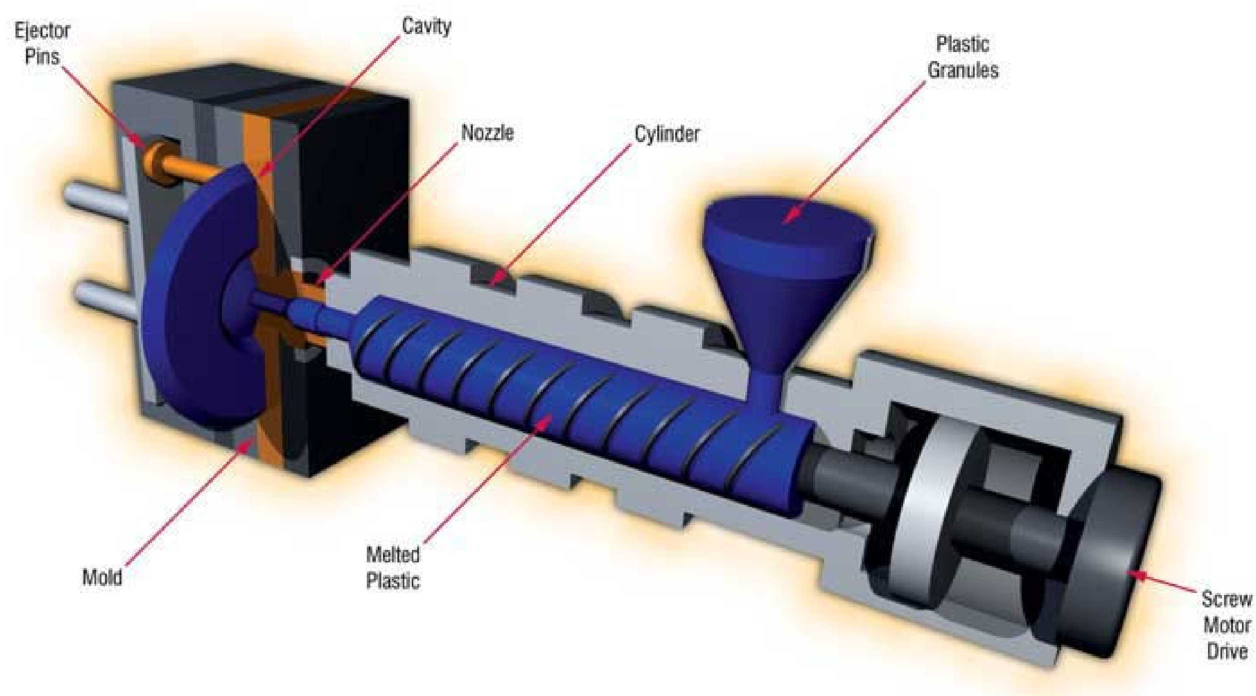


Figure 27: Injection Molding Diagram

Because the mechanism is in three pieces, we require labor to assemble them together with a fastner such as a screw. Once the connector is attached to the heel, an assembler must attach the heel base to the actual shoe. Our sponsor has suggested that she would like to begin production with about 10,000 pairs of these heels.

13 **Testing**

13.1 **Test Plan**

At the beginning of the semester the group decided on tests that would have to be carried out during the semester. These tests included a Function Test, Tension Test, Compression Test, Wear Test, and Accelerated Life Cycle Test. The test plan that was created by the team listed three sections for each test. The three sections are the description of the test, what is needed to perform the test, and who the lead team members of the test are. These tests are in the order that they are performed.

1) Function Test
    a. Description: This will be a test to make sure that the heel functions as it was designed to do. The heel will be attached to a shoe(Naturalizer). The locking

mechanism will be tested. This test will be used to make sure that the heel can only be inserted into the shoe in one orientation.

   b. What is needed to perform this test: Buy two pairs of Naturalizer Heels in a size 5.5 and two pairs in a size 9. 4 Heels need to be made from rapid prototype material.
   c. Lead Team Members: Kayla and Tabitha

2) Accelerated Life Cycle Test
   a. Description: A mechanical system will be designed to twist the high heel on and off 14,000 times. The wear will be analyzed using a caliper with a digital readout
   b. What is needed to perform this test: A unique machine that will simulate the inserting and twisting of the heel into the base. A base and a connector that are made out of different materials.
   c. Lead Team member: Nick
3) Compression Test
   a. Description
      i. Test to Design Specification: This will test the heel to see how it holds up under the compression force that is specified in the design specifications. The heel will be put in a fixture which will be attached to the Instron machine. One the heel has been compressed it will be analyzed for wear and damage
      ii. Test to Failure*: This will test to see at what force the heel will either break or become too deformed that it cannot function properly
4) Tension Test
   a. Description : This test will be used to see how the heel holds up under tension
      i. Test to Design Specifications: This will test the heel to see how it holds up under the tension that is specified in the Design Specifications.
      ii. Design to Failure*: This will test how much tensile force the heel can absorbed without breaking. The failure type as well as where the heel breaks will be analyzed.
5) Wear Test**
   a. Description: This will test to see how the heel will hold up under normal every day wear. Tabitha and Kayla will wear a pair of high heels all day for one day and the heels wear will be analyzed. Also comfort and durability will be analyzed.
   b. What is needed to perform this test: Buy two pairs of Naturalizer Heels in a size 5.5 and two pairs in a size 9. 4 Heels need to be made from rapid prototype material.
   c. Lead Team Members: Tabitha and Kayla

*This aspect of the test was not able to be done because of the length of time it takes to have different heels made. It was decided not to test parts to failure because of the limited number of parts that were able to be made by the machine shops.

**Not performed due to safety concerns. This test was not able to be performed because of the length of time to have the heel made. The heels were able to be made quickly using the rapid prototype machine and material but this material is not strong and may have broken and caused an injury to a team member during the test.

13.2 Test Sheet

A test sheet was designed by Tabitha. This is an effective and organized way to compile and analyze all of the different results that will be found performing the different tests. The test sheet is also a good way to keep a record of what team members performed what tasks. As is shown in the actual test sheet it has spots for the equipment required, and spots for setup images. These can be used to make sure the test is performed the same way if it has to ever be performed again.

Dynamic Heels: Test Sheet | 2011

Test Name			
Description			
Team Members Performing Test			
Design Specification(s) to be Tested			
•			
Equipment Required			
•			
Date Performed	**Beginning Time**	**End Time**	
Results			
Setup Images (If Available)			

Figure 28: Blank Test Sheet

13.3 **Functionality Test**

A functionality test was performed to determine if the heel would work when I was put on the bottom of the shoe. The original twist and lock prototype:

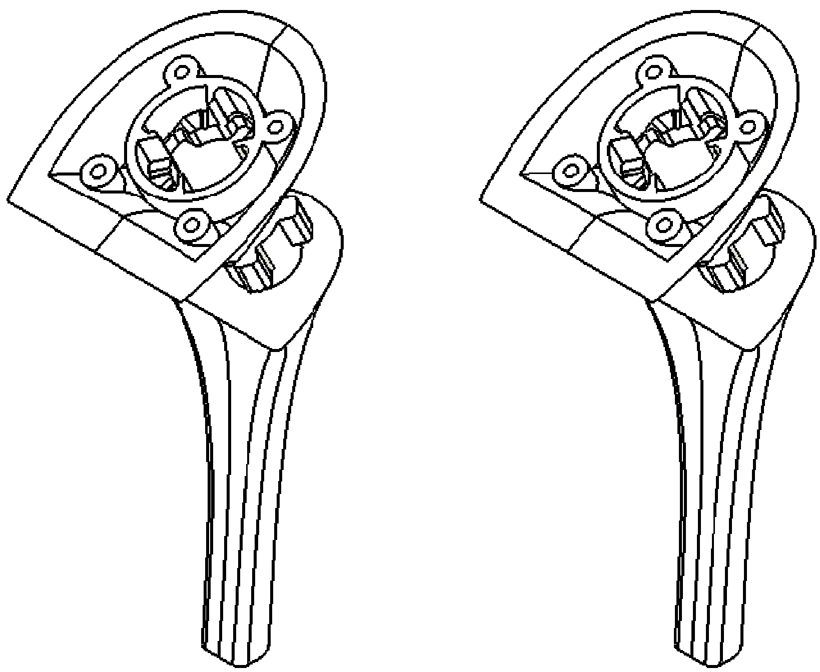
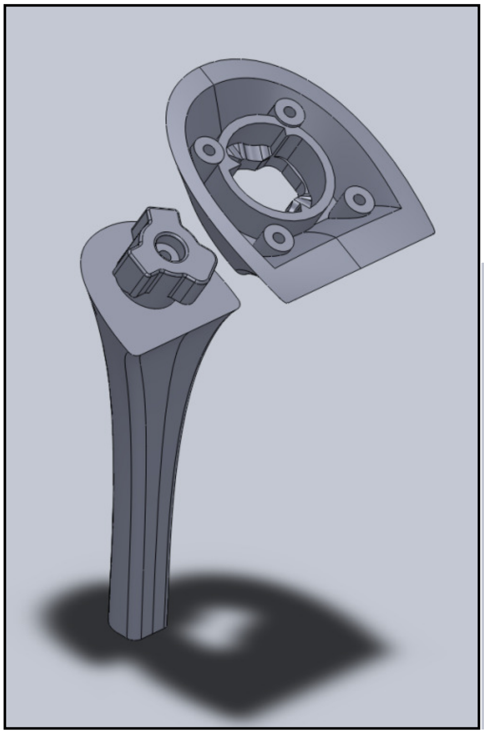


Figure 29: Original Twist and Lock

13.4 **Redesign 3**

After looking at the results of the first functionality test the first redesign involved changed the amount of nodes that were on the connector piece and the size of the bumps that would be inserted in the locking mechanism. As shown in Figure 30 the new Twist and Lock only had three nodes and one of them was a different size. The base of this design is shown in Figure31 and clearly shows that one of the nodes is wider than the others.

By switching from four nodes to three nodes, the heel will only turn about 60o. Each connector can be made with more surface area. This allows for the connector piece to be bigger and not just shear off the first time the heel is turned. Originally the connector was just a small bump in the middle of the nodes but now the connector is a bump that extends from one side of the node to the other. (Figure in wear test)



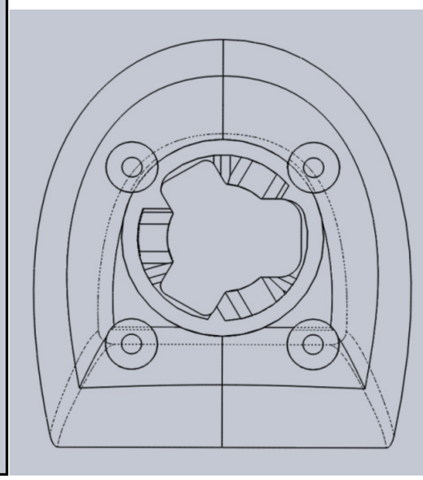
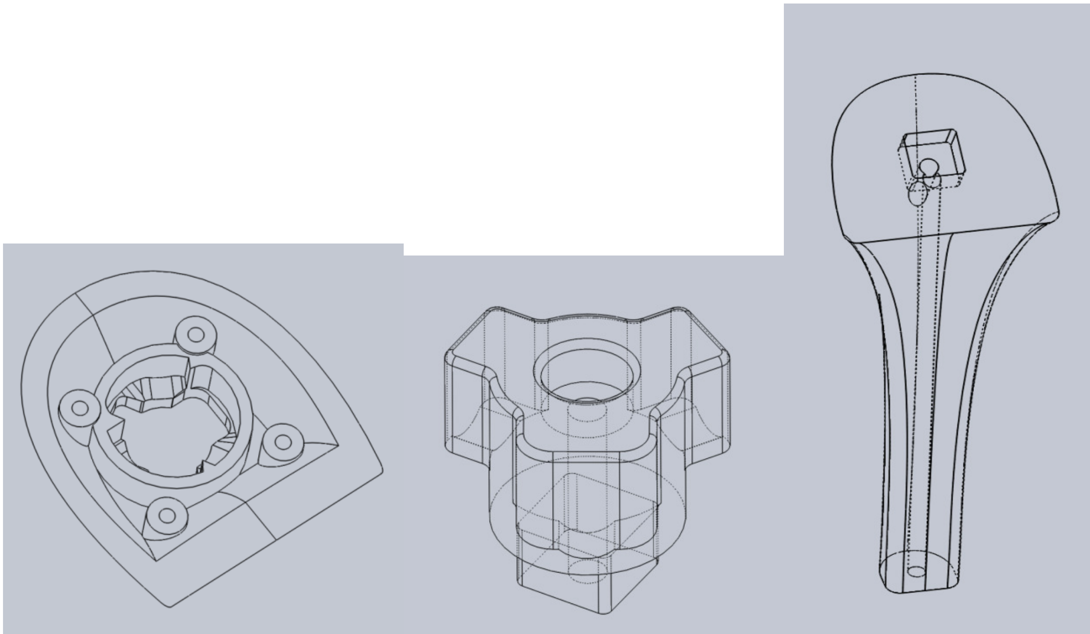


Figure 30: Twist and Lock RedesignedFigure31: Base of 3-Node Connector

13.5 **Redesign 4**

After this initial functionality test and redesign there was still a problem with the manufacturability of the parts. When the part was made with rapid prototype material the heel and the base could be two separate parts and there is not an issue. Support material can be simply added to the space under the connector and dissolve after the part has been made. Trying to machine the part in a machine shop proves more difficult. If the part is kept with two different pieces there is really no way to get between the heel and the connection nodes in order to make the bumps for the connector.

The second redesign was to change the heel from two pieces to three pieces. The new design kept the heel separate from the connector piece and had a base piece. These designs are shown in Figure 33, and Figure 32.



There were certain issues that were magnified when the heel was inserted in the base. These issues were the locking mechanism was not strong enough and the heel could be inserted at any orientation.

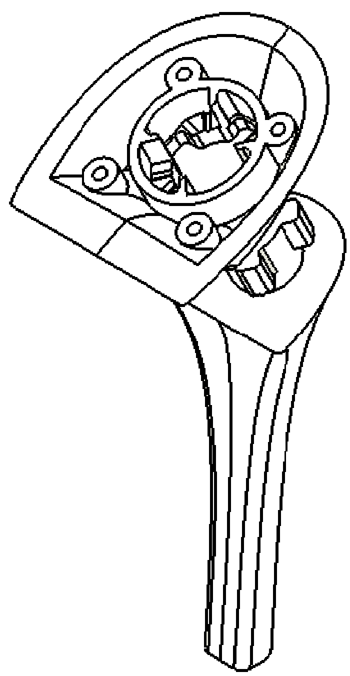
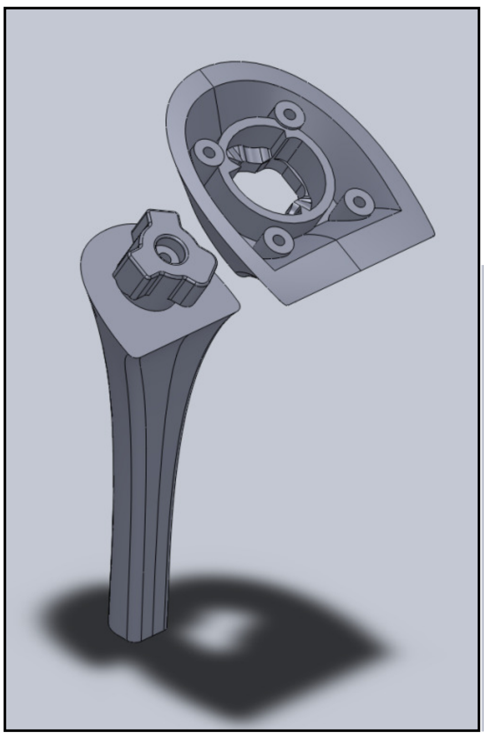


Figure 29: Original Twist and Lock

13.6 **Redesign 3**

After looking at the results of the first functionality test the first redesign involved changed the amount of nodes that were on the connector piece and the size of the bumps that would be inserted in the locking mechanism. As shown in Figure 30 the new Twist and Lock only had three nodes and one of them was a different size. The base of this design is shown in Figure31 and clearly shows that one of the nodes is wider than the others.

By switching from four nodes to three nodes, the heel will only turn about 60°. Each connector can be made with more surface area. This allows for the connector piece to be bigger and not just shear off the first time the heel is turned. Originally the connector was just a small bump in the middle of the nodes but now the connector is a bump that extends from one side of the node to the other. (Figure in wear test)



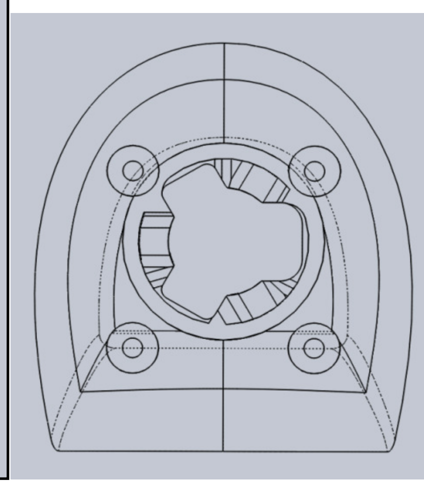


Figure 30: Twist and Lock RedesignedFigure31: Base of 3-Node Connector

13.7 **Redesign 4**

After this initial functionality test and redesign there was still a problem with the manufacturability of the parts. When the part was made with rapid prototype material the heel and the base could be two separate parts and there is not an issue. Support material can be simply added to the space under the connector and dissolve after the part has been made. Trying to machine the part in a machine shop proves more difficult. If the part is kept with two different pieces there is really no way to get between the heel and the connection nodes in order to make the bumps for the connector.

The second redesign was to change the heel from two pieces to three pieces. The new design kept the heel separate from the connector piece and had a base piece. These designs are shown in Figure 33, and Figure 32.

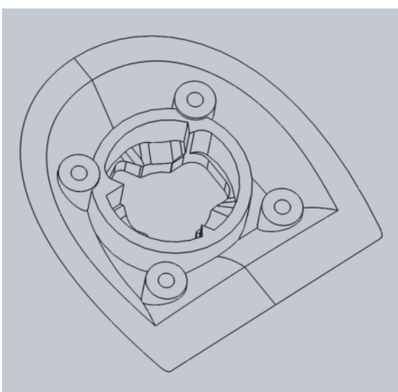


Figure 33: Base Piece

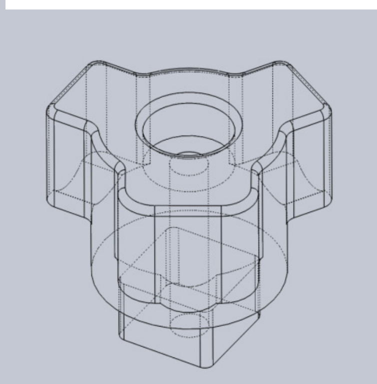


Figure 34: Connection Piece

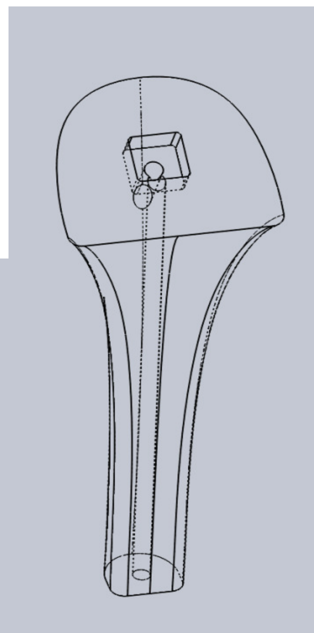


Figure 32: Heel Piece

After the second set of redesign it the twist and lock heel was mounted on a Naturalizer shoe. The process involved taking a heel off an existing shoe without damaging the cushioning and then screwing the new rapid prototype heel on the shoe and gluing the padding back down. The shoe that was used is show in Figure 35. This figure shows the different views of the shoe without the heel. Figure 36 shows the final heel attached to the Naturalizer shoe.

Figure 35: Side, Top, and Bottom View of Naturalizer Shoe without Heel

Figure 36: Naturalizer shoe with twist and lock heel

13.8 **Redesign 5**

The only issue that was found when the heel was inserted the heel was free to wiggle . This was caused because the connector did not fit in the hole perfectly and there was too much room above the connector and it was not a snug fit when it was inserted into the base. The first attempt to fix this problem was to insert a spring on the bottom of the shoe that would push back against the heel when it was inserted to hold it in place. The spring that was used was just a spring from a retractable pen and it seemed to work well. One problem with the spring was that it is a compression spring and the twist and lock design introduced a torsional force which effectively destroyed the effectiveness of the spring after turning it a few times. Even after the integrity of the spring had been compromised the force it exerted on the heel was enough to keep the heel stable.

Another reason why the spring would not be an optimal design is that it would increase the cost of the shoe when a worker has to insert the spring in the bottom of the base. For this reason it would not work to just insert a torsion spring in the base. Another solution that was found was to put a small rubber mat at against the shoe in the base of the heel. The rubber mat is thickness of rubber here and would push against the connector to create a good fit.

The drawbacks of the mat is that it pushes hard enough against connector that more force needs to be applied to snap the heel into place. It also creates a line because the heel and the base part are touching anymore. This problem can be resolved in a variety of ways. If one was to wrap a shoe in leather this line might work so that the leather does not wear. Small adjustments can be made and a lip of the heel can be made to “ close the gap”.

Dynamic Heel Accelerated Life Test:

Design:

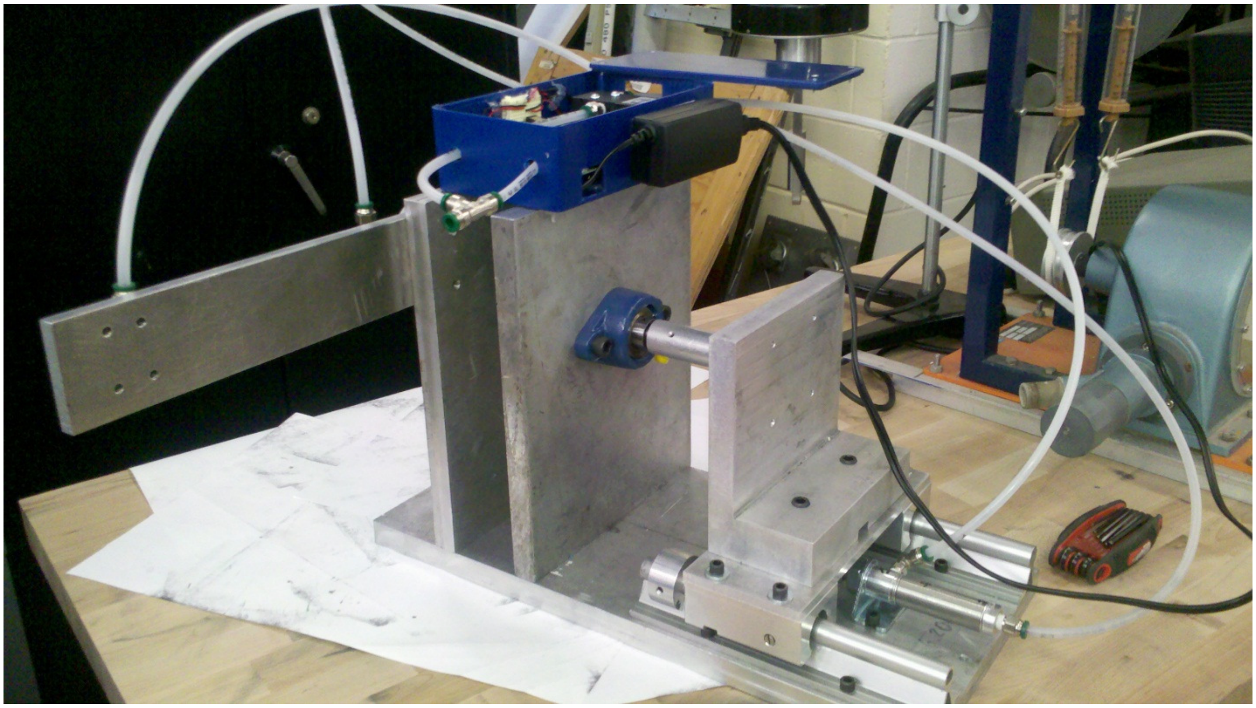


Figure 37: Completed Wear Test Machine

The twist and lock heel design needed a test that would check the wear that would occur over the life of the connection piece. There was not a machine that was available at URI that would simulate this so a custom machine had to be designed and fabricated.

The design of this machine was originally was just a double acting rotating piston with a lever arm to check the wear on the locking mechanisms. This design would have ignored the fact that the heel needed to be inserted into the base of the heel. With this initial design the only wear that would have occurred would occur with the locking mechanism and the height of the connector (Figure 38). The machine was redesigned to accommodate for a double acting linear acting piston and a double acting rotating piston. The linear actingpiston will simulate taking out and inserting the heel into the base of the heel andthe rotating piston will simulate actually locking the heel in place. The frame of the device needed to be made out of aluminum or steel to allow for the sufficient slamming action of a piston. Ideally the fixture would be made out of steel but that would render the testing fixture too heavy to be lifted and moved by a single person. The completed machine is shown in Figure 37

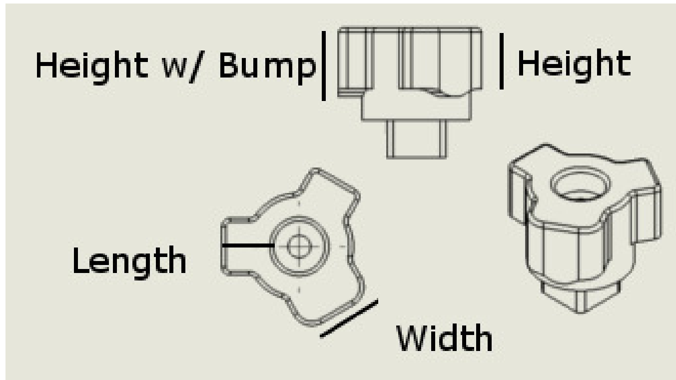


Figure 38: Connector Dimensions

Additional considerations that were taken into account during the design phase of the machine were the length of the lever arm, position of the pistons, and how far each of the pistons would be allowed to travel. If the triangle in Figure 39 is used as a representation of the lever arm, length AB would be the piston stroke. The stroke on the rotating piston used was 5 inches so using the relation AC=BC=a, and $AB = \sqrt{2}a$, the lever arm was determined to be 3.53 inches.

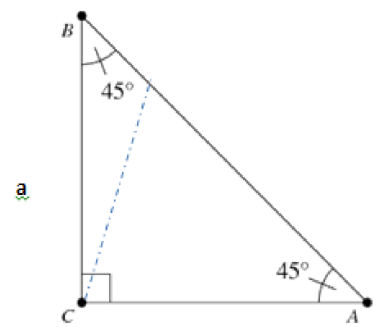


Figure 39: Isosceles Triangle

The first twist and lock design had 4 connectors that were shorter so the piece could rotate 90 degrees. Using this information an initial lever arm length could be constructed by the above relations. During one of the first redesigns the connector piece was changed from 4 connectors to 3 connectors. This design change meant that the piece only had to be rotated 60 degrees and a rotation of 90 degrees would over rotate the heel. This changed was accounted for in the machine by putting a stop when the heel was fully rotated. This is was the dotted line in Figure 39 shows. The final piston, lever arm and stop are shown in Figure 40

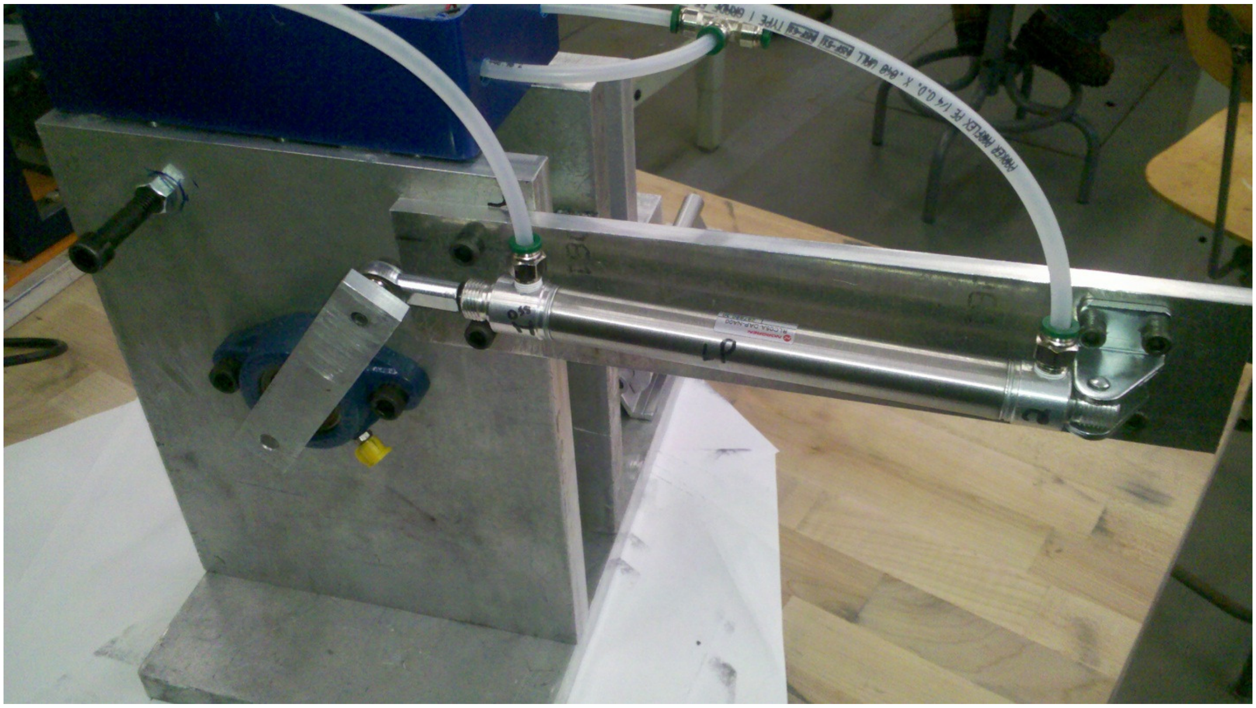


Figure 40: Rotating Piston, Lever Arm and Stop

Additional stops were needed for the linear piston. These stops were needed so that the slamming of the heel pieces would not cause the machine to break. The two stops were fabricated using a horizontal band saw and a lathe. In order to ensure the stops did not move on the rail, two set screws were inserted on each stop. These set screws would go on the rails to prevent sliding. Preventing the slamming is less important on an aluminum base test but on a test performed with Nylon or Delrin it is important so the base parts do not break.

A single test will consist of moving the linear piston forward to insert the heel in the base. Then the rotating piston will turn Clockwise and then CounterClockwise. This test will be repeated 14000 times. The locking mechanism will be checked at different intervals during the test and different measurements will be taken with a caliper with a digital readout. 14000 test cycles were determined by assuming the life of a heel would be 10 years and the heel locking mechanism would be engaged and disengagedapproximately 4 times per day. This of course is a very high estimate of the number of times that a heel mechanism will be engaged. Even a life span of 5000 times is high. The pistons will be controlled by 2 solenoid valves. These solenoid valves will be in turn connected to a Blackwidow Arduino microcontroller. This microcontroller will be in charge of turning the solenoid on and off. The arduino will be turned on by a custom iPod app called Wear Test.

Electronic Circuits: An important part of this machine will be the electronic setup that is controlled by the arduino board. A Relay Shield is used to upscale the voltage to control the solenoids. The Relay Shield needs 9V to run and the arduino microcontroller needs 5V to run. A plug that gives 9V is plugged into the wall and the other end is plugged into a breadboard that is connector to a voltage regulator. The job of the voltage regulator is to take the 9V from the wall and convert it to 5V. Using this regulator the Arduino Shield and the Relay Shield can be power only using 1 outlet.

When the Relay Shield is powered it needs to be connected solenoids which control the air flow. Which valve is opened and for how long is controlled by the arduino code. When the solenoid is opened one way the piston will engage and when the solenoid is moved the other way the piston will return to its normal position.

The black widow arduino microcontroller also has a WiFi card that is attached to it. The WiFi card uses communication standard 802.11b and supports a data rate of 2 mbps. Using certain libraries allows for the BlackWidow to act as its own webserver. This means that it will have its own address. In the code this address is 192.168.1.125. Different pages can then be assigned to this address. For example 192.168.1.125/ten will tell the arduino to perform 10 cycles and the address 192.168.1.125/thousand will tell the arduino to perform 1000 cycles. After a testing cycle has occurred, the arduino board has to be unplugged and plugged back into the wall. This step is to reset the wireless because the relay board is causing interference with the WiFi interrupt. All of the relay boards, solenoids and electric components can be seen in Figure 41. The arduino and relay board are on the left, the air solenoids are on the right and the voltage regulator is on the breadboard at the top of the figure.

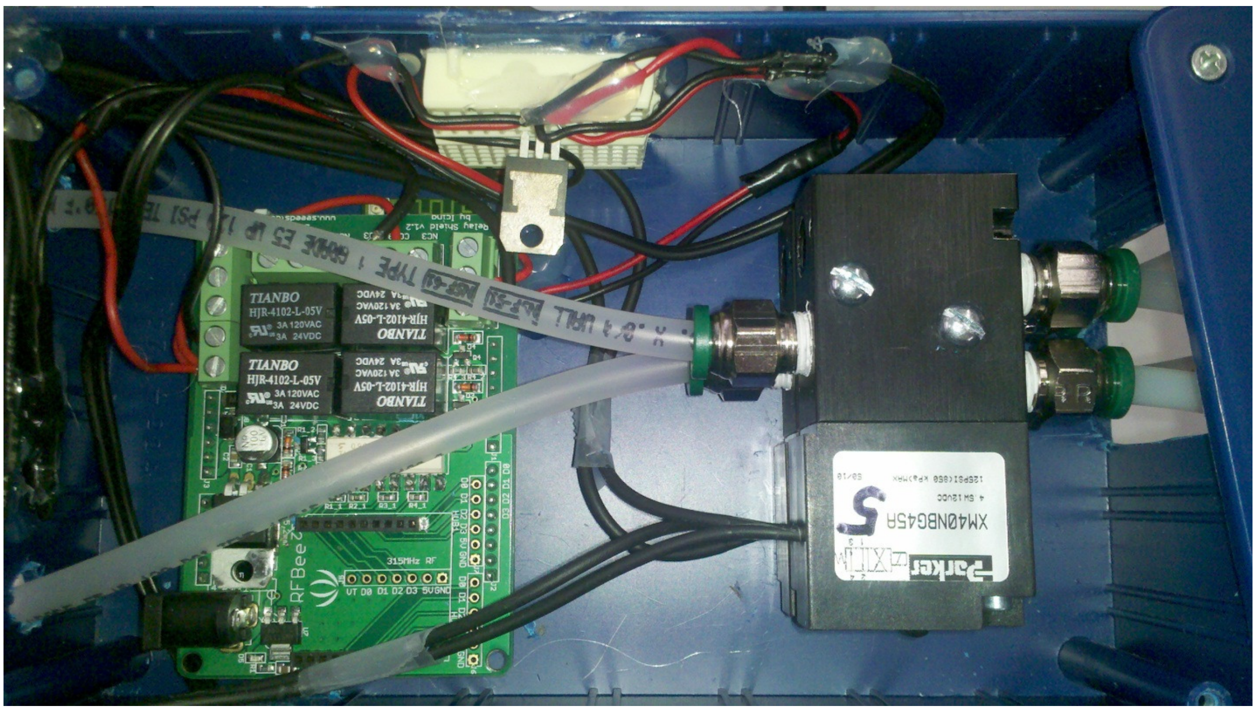


Figure 41: Electronic circuitry of Wear Testing Machine

The arduino can also be connect to a network (infrastructure) or broadcast its own signal(adhoc). There are advantages and disadvantages to both of these options. For reliability it is easier to use the infrastructure mode. This is the mode that was run during the in-class presentation. The WiServer will connect to a router and then any computer or wireless device (iPhone, mp3 player, etc) can access the arduino server by simply going to the website (192.168.1.125/thousand). Using infrastructure mode it is possible to control arduino as long as the wireless device is connected to the router which typically have a range of around 100ft. If the arduino is broadcasting in ad-hoc mode then it talks directly to the wireless device. This mode was used in lab when the tests were actually being performed. The advantages of this mode is that a router is not needed but this means the range of the wireless signal is reduced drastically ~5-10 ft. Another problem is that in order to connect to the adhoc a static ip address needs to be assigned to the wireless device. This is rather easy to change with an iPhone or iPod but can be more difficult with other wireless devices (laptops, Android cell Phones). For this reason a iPod was chosen to control the machine.

A custom iPod app was built to make choosing the correct site URL easier. Rather than going to Safari and typing 192.168.1.1/thousand one can just select the iPod App and choose the appropriate amount of cycles that is desired. The preset buttons allow for 5,10,100,200,500, and 1000 cycles. The app will call the appropriate webpage in a hidden view so the app will stay on the screen. The App is shown in Figure 42: Ipod App

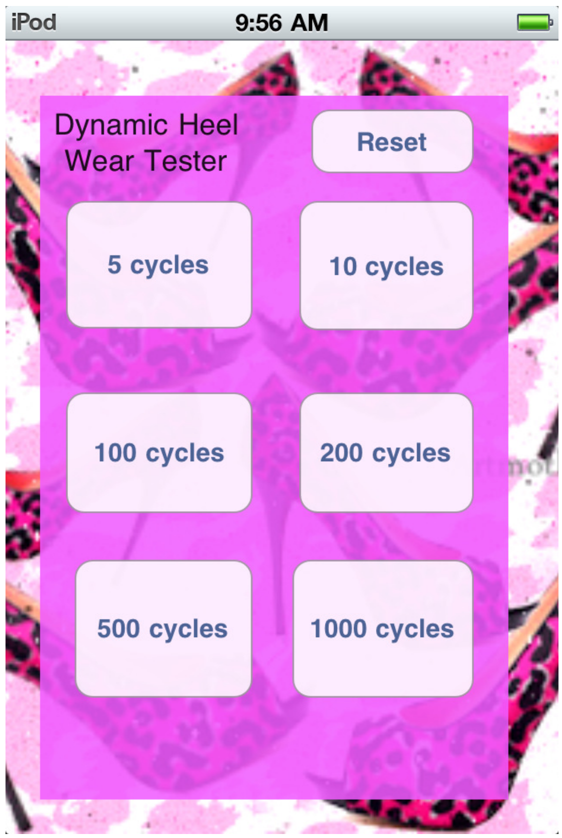


Figure 42: Ipod App

Major Parts

Double Acting linear piston: In charge of moving the forwards and backwards to simulate inserting the heel into the base. (McMasterCarr Part No: 6498K151)

Double Acting rotating piston: In charge of rotating the piston after it has been inserted in the base(McMasterCarr Part No: 6498K151)

Solenoids: Controls the air flow to the pistons based off command it receives through arduino and relay shield(Part Number XM40NBG45A) See Appendix for more information on the Solenoids.

Slider and Rails:Linear bearing that uses dry lubrication technology to move the heel forward and backwards. The diameter of the rail is 16mm. (Donated by Igus part numbers are OTA-03-16 and AWUM-16).

Aluminum Block: a 6”x6”x3” piece of 6061 Aluminum. The weight of this piece was originally 10.54lbs (~4.78kg). To make it light this piece was cut into an L shape. The piece of aluminum that was removed was approximately 6”x2.5”x4.5”. Its weight was 6.57 lbs (~2.98kg) or approximately 62% of the original weight of the slab. This reduction in weight would reduce the weight on the bearings making them easier to slide (McMasterCarr Part No: 895k568)

Flange Mounted Steel Ball Bearing: Used for alignment of the steel rod, connector, and base with flange. This piece can be adjusted 2^{o} to make sure all the pieces fit together perfectly. (McMasterCarr Part No: 5968k71)

Heel parts:

The heel parts were modified to make them easier to manufacture. (**See figure)**The connector piece was inserted on a custom adapter that was able to fit on the steel shaft. One side of the connector had set screws so the steel shaft would not move. This change to the heel made the test easier because the actual heel is not a straight cylinder. If an actual heel was used then additional considerations would have had to be taken to make sure everything was lined up. These considerations would be unnecessary for this test because no wear will occur on the aesthetic portion of the heel.

The base of the heel was also changed to accommodate this test. Instead of making the base’s aesthetically pleasing part, only the connection part was made. A flange part was also put on the base to allow the heel to attach to the Aluminum block.**figure**

Precision Metal Shaft: A ½ inch steel shaft was used for the rotation part of the machine. When the rotating piston was engaged it would rotate this shaft. In order to ensure that the shaft was only rotated by the piston and did not over rotate part of the circular shaft was cut and made flat. Then a set screw was put in to make ensure no extra rotation. (McMasterCarr Part No: 5947k25)

Arduino Black Widow: Arduino microcontroller that comes with a WiFi module to allow for wireless communication with the iPod.

Arduino Relay Shield: A Relay Shield that can fit on the Arduino that will upscale the Power that can be outputted by the Arduino board allowing it to run the Solenoids. See appendix for detailed information on the Relay Shield.

iPod App- A custom iPod App was developed to allow the machine to turn on and run different amount of cycles in increments of 5, 10, 100, 200, 500, or 1000.

Testing- Each set of tests will take approximately 1 week to perform. The reason for the length of the test is that the test could only be run when a member of the team was on campus in order to take measurements and in order to make sure nothing went wrong with the machine. One cycle of the test takes approximately 5 seconds and 1000 cycles take approximately 90 minutes. During a course of the day if the test is run from 9-4 only about 4000 cycles could occur.

Future Work: This machine was designed to perform an accelerated life test on the base of the heel and its connector. In the period of time this machine was fabricated, the machine is constructed well but there are still some issues that could be improved. One issue that the entire L shape block and has to be removed in order to take a measurement. This takes a while to accomplish and introduces a new error when the connector and flange piece are realigned. If they are not realigned exactly because of the force that the piston run at the connector piece (which is not as strong) could experience a lot more wear than could be expected. Other issues that could be addressed for this machine but did not have priority due to time constraints of the project would be to identify where the interference is occurring in the electrical components of the machine. Another issue that could be addressed is how hard the pistons are slamming. This issue could be addressed with some pressure regulators. Use of this regulator would limit how hard the pistons would slam and could reduce the machines movement on the table. One other issue that would have to be addressed if this device was ever going to be used is enclosing the moving parts of the pistons to avoid injury. Right now the piston is hitting a stop with force that may cause an injury to someone if their hand or fingers were inadvertently put in its way. Additionally more tests could be carried out with different combinations of materials.

Results: This machine was designed to test the wear of the heel connector and the base of the heel. Ideally differentcombinations of Aluminum, Nylon, and Delrin would be used for the base and connector. However due to time constraints and the amount of time the machine shops took to fabricate these parts the only combinations of a Nylon Connector/Aluminum base and Nylon Connector/Delrin could be fabricated and tested.

Aluminum Base- Nylon Connector

***All Values in mm**

	1*				2*				3*			
Cycles (n)	Length	Height	Height w/bump	Width	Length	Height	Height w/bump	Width	Length	Height	Height w/bump	Width
0	6.5	7.34	7.81	9.7	6.51	7.21	7.92	7.4	6.5	7.21	7.93	7.45
200	6.5	7.31	7.8	9.65	6.51	7.19	7.89	7.21	6.45	7.2	7.87	7.4
400	6.5	7.3	7.77	9.65	6.5	7.21	7.87	7.21	6.41	7.18	7.89	7.38
600	6.5	7.2	7.7	9.65	6.5	7.2	7.9	7.2	6.4	7.16	7.88	7.39
800	6.51	7.21	7.7	9.64	6.51	7.19	7.88	7.2	6.4	7.16	7.89	7.38
1000	6.49	7.2	7.69	9.64	6.5	7.19	7.87	7.3	6.4	7.18	7.89	7.38
2000	6.45	7.23	7.7	9.64	6.41	7.2	7.85	7.21	6.37	7.19	7.9	7.36
3000	6.48	7.21	7.71	9.59	6.37	7.2	7.83	7.21	6.38	7.19	7.87	7.31
4000	6.5	7.2	7.7	9.58	6.4	7.21	7.8	7.2	6.39	7.16	7.87	7.26
5000	6.5	7.15	7.65	9.54	6.4	7.2	7.82	7.07	6.39	7.15	7.9	7.36
6000	6.47	7.17	7.68	9.55	6.4	7.24	7.83	7.05	6.42	7.17	7.9	7.31
7000	6.45	7.17	7.66	9.55	6.38	7.22	7.79	7.03	6.39	7.19	7.9	7.02
8000	6.44	7.17	7.63	9.54	6.4	7.19	7.8	7.01	6.38	7.17	7.9	7.03
9000	6.44	7.16	7.64	9.54	6.39	7.18	7.8	7	6.38	7.18	7.91	7.02
10000	6.43	7.16	7.63	9.52	6.4	7.16	7.81	7	6.38	7.18	7.9	7.02
11000	6.43	7.17	7.63	9.51	6.39	7.16	7.8	7	6.38	7.17	7.9	7.03
12000	6.44	7.16	7.59	9.47	6.4	7.18	7.8	7.01	6.39	7.18	7.84	7.03
13000	6.43	7.16	7.59	9.47	6.41	7.18	7.81	7	6.4	7.18	7.85	7.02
14000	6.44	7.16	7.58	9.47	6.4	7.17	7.8	7	6.4	7.19	7.85	7.04

Table 4: Raw data of the length taken of the connector after each cycle test (all values in mm)

	1*				2*				3*			
Cycles (n)	Length	Height	Height w/bump	Width	Length	Height	Height w/bump	Width	Length	Height	Height w/bump	Width
0	0	0	0	0	0	0	0	0	0	0	0	0
200	0	0.03	0.01	0.05	0	0.02	0.03	0.19	0.05	0.01	0.06	0.05
400	0	0.04	0.04	0.05	0.01	0	0.05	0.19	0.09	0.03	0.04	0.07
600	0	0.14	0.11	0.05	0.01	0.01	0.02	0.2	0.1	0.05	0.05	0.06
800	-0.01	0.13	0.11	0.06	0	0.02	0.04	0.2	0.1	0.05	0.04	0.07
1000	0.01	0.14	0.12	0.06	0.01	0.02	0.05	0.1	0.1	0.03	0.04	0.07
2000	0.05	0.11	0.11	0.06	0.1	0.01	0.07	0.19	0.13	0.02	0.03	0.09
3000	0.02	0.13	0.1	0.11	0.14	0.01	0.09	0.19	0.12	0.02	0.06	0.14
4000	0	0.14	0.11	0.12	0.11	0	0.12	0.2	0.11	0.05	0.06	0.19
5000	0	0.19	0.16	0.16	0.11	0.01	0.1	0.33	0.11	0.06	0.03	0.09
6000	0.03	0.17	0.13	0.15	0.11	-0.03	0.09	0.35	0.08	0.04	0.03	0.14
7000	0.05	0.17	0.15	0.15	0.13	-0.01	0.13	0.37	0.11	0.02	0.03	0.43
8000	0.06	0.17	0.18	0.16	0.11	0.02	0.12	0.39	0.12	0.04	0.03	0.42
9000	0.06	0.18	0.17	0.16	0.12	0.03	0.12	0.4	0.12	0.03	0.02	0.43
10000	0.07	0.18	0.18	0.18	0.11	0.05	0.11	0.4	0.12	0.03	0.03	0.43
11000	0.07	0.17	0.18	0.19	0.12	0.05	0.12	0.4	0.12	0.04	0.03	0.42
12000	0.06	0.18	0.22	0.23	0.11	0.03	0.12	0.39	0.11	0.03	0.09	0.42
13000	0.07	0.18	0.22	0.23	0.1	0.03	0.11	0.4	0.1	0.03	0.08	0.43
14000	0.06	0.18	0.23	0.23	0.11	0.04	0.12	0.4	0.1	0.02	0.08	0.41

Table 5: Change in length of each of the dimensions (all values in mm)

These two tables show the values that were taken during each measurement. The measurements were taken with a caliper with a digital readout to the second decimal place. Table 4 refers to the length that was given by the calipers. Table 2 is the original length subtracted from the length at every testing interval. It should be noted that for the Aluminum- Nylon test that was performed the Nylon part of the heel was preworn because it was used in the fabrication of the machine. While aligning the machine sometimes the piece would try to pull out while it was still engaged in the heel.

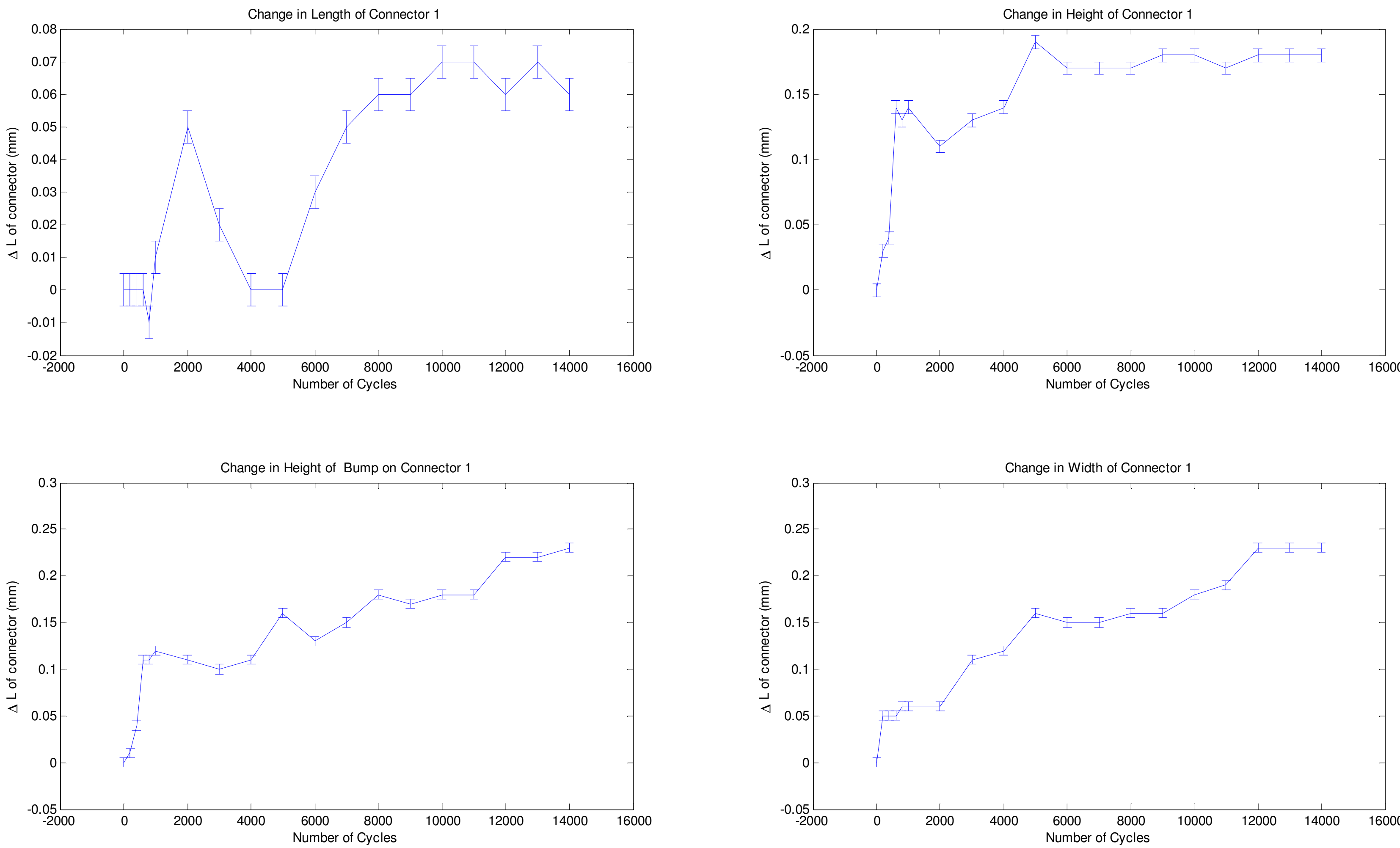


Figure 43: Change in the lengths of the biggest connector(Connector 1)

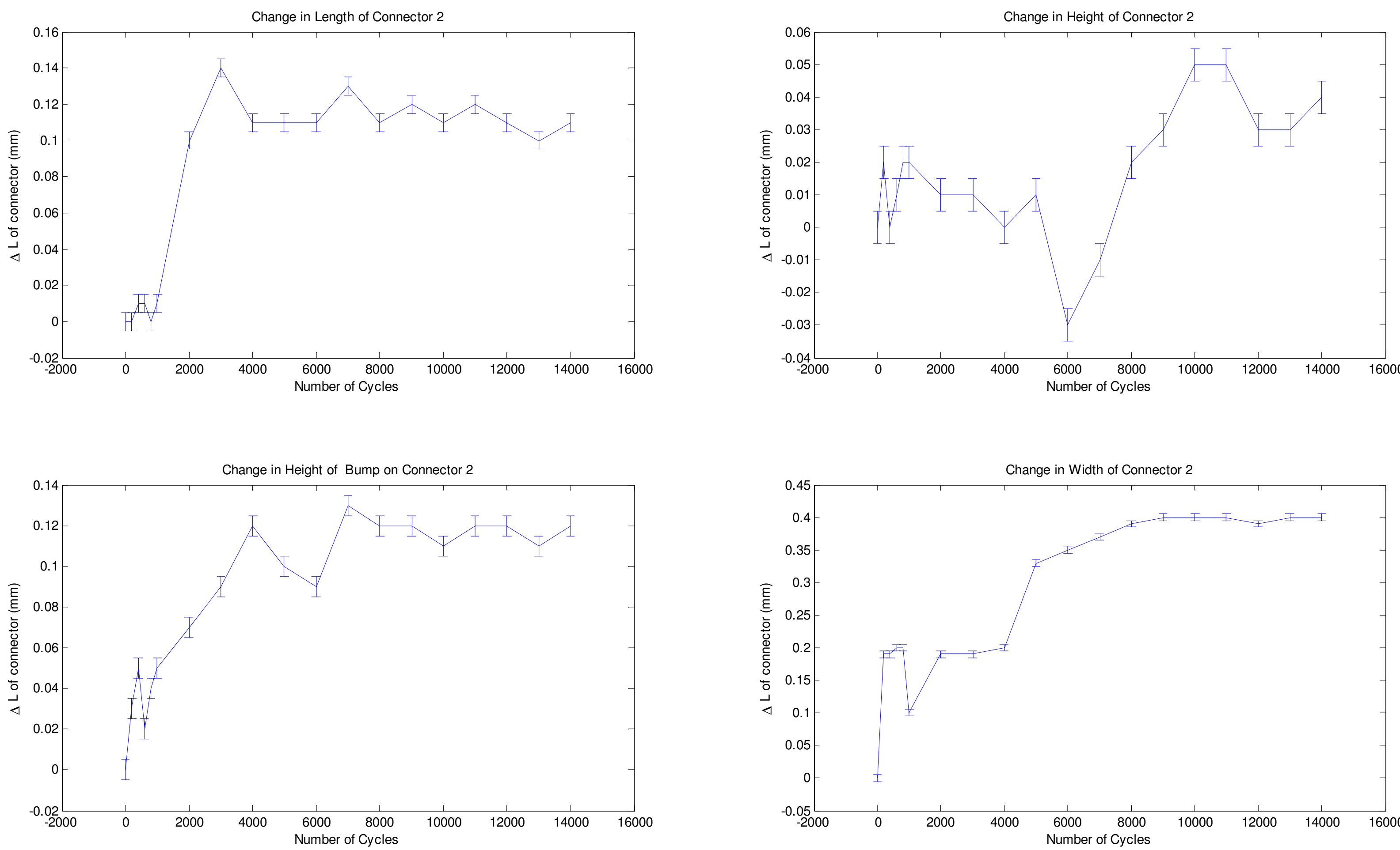


Figure 44: Change in the lengths of connector 2

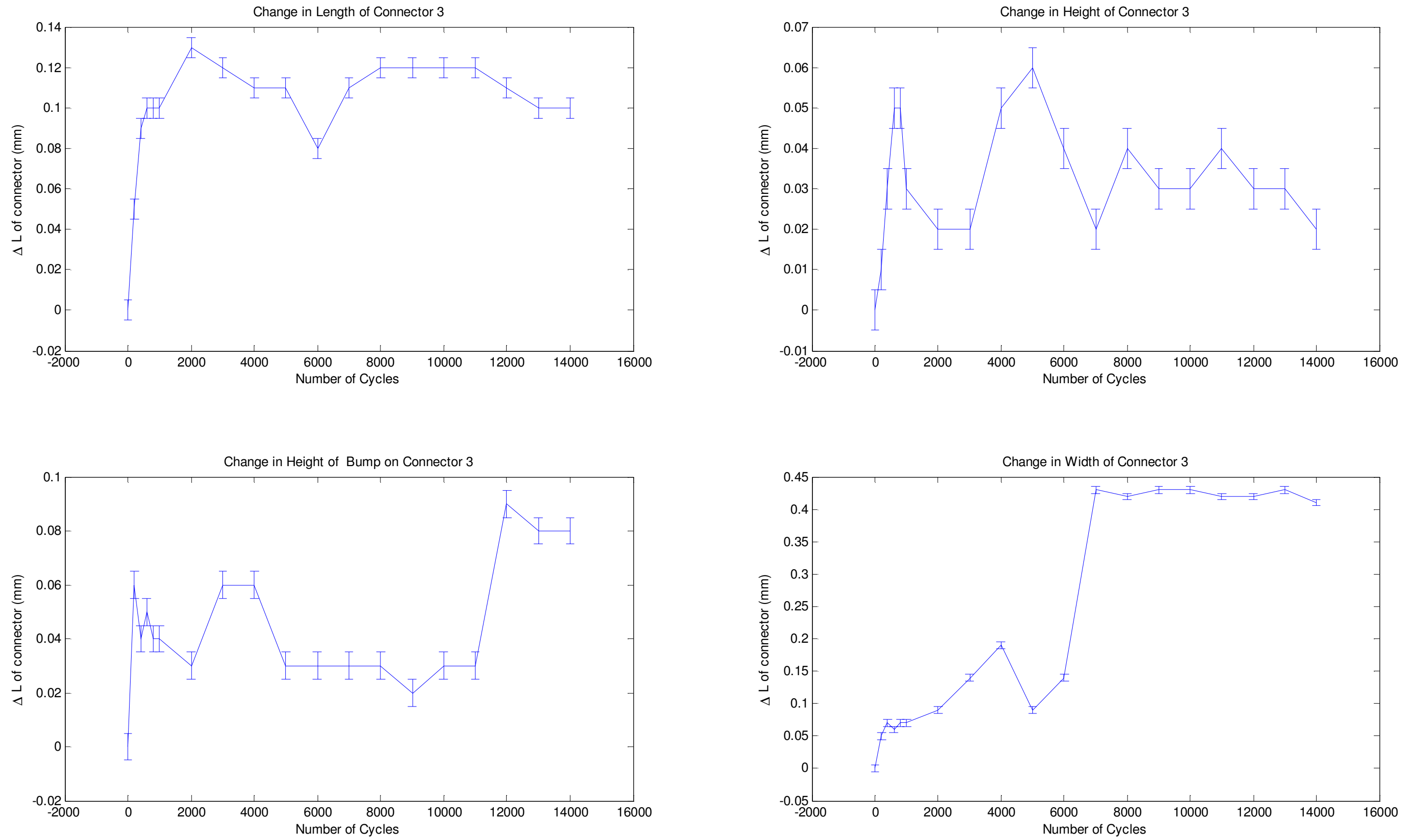


Figure 45 Change in the lengths of connector 3

Looking at all of these graphs it is evident that the heel undergoes some initial wear and then the rate of wear decreases. Most of this wear seems to occur before the 2000 cycles. However the amount of wear that occurs is very small (normally under 2/10 of a mm). Most of the fluctuation in the measurement occurs due to measurement error with the calipers. This is very evident when the wear rate is going down rather than up because it is not possible for the shoe to gain material. The error bars that were used were .005mm which is half of the smallest scale division of the caliper (.01mm). It should also be noted that around the 2000-3000 cycle test the way that the connection piece was measured was changed. Instead of trying to measure the connection piece on the machine it was taken off to ensure a more accurate readout. This in turn created could have contributed to the abrupt change in the change in length that the graphs show. It could also be attributed to more wear because the base and connector had to be realigned every time the test was performed.

On the biggest connector the wear that occurred seemed to happen with the height and width of the connector. The change in the height with the bump seemed to continue to wear even after 14000 cycles had occurred. The most significant wear occurred on the width of the connectorLooking at Figure 43 the majority of the wear seemed to occur around 6000-8000 cycles. Figure 44 shows that the same basic wear occurs and by the 6000-8000 cycle the wear essentially does not change. Again the most significant wear occurred on the width of the connecter. Figure 45 shows very little wear in the height of the connector with or without the bump. Again the most wear occurs in the width of

This data is interesting because before the test it was thought the most significant wear would occur with the height of the connector. As it turns out the most wear occurred at the width of connector. This may have happened because of the force the linear piston would move the connector into the base if everything was not perfectly lined up.

13.9 Additional Testing

It was the intention since the beginning of the semester to perform multiple tests with the machine. Another flange piece was submitted to Joe the machinist at the end of March/beginning of April. The group was informed the week of April 18th that a part out of Delrin could not be manufactured until raw material of Delrin was ordered. Due to the time in the semester the team was informed this part could not be made it was not possible to have this part made and run another test.

Conclusions: From performing these tests it was easy to tell that Aluminum could not be used for the base of the shoe as originally thought. One reason for this is how sharp the corners of the Aluminum were. This could be dangerous for a few reasons. One is that someone might be able to cut themselves if they put their finger inside the hole when no heel is inserted in the base. Second, when the heel was inserted even one time, it seemed that part of it would shave off. This was directly attributed to how

Test Name

Wear Test Aluminum

Description

Accelerated Life Test to determine the wear that is done after 14000 cycles on a connector piece

Team Members Performing Test

Nick DiFilippo			

Design Specification(s) to be Tested

- If the locking mechanisms will function after being used 14000 times.

Equipment Required

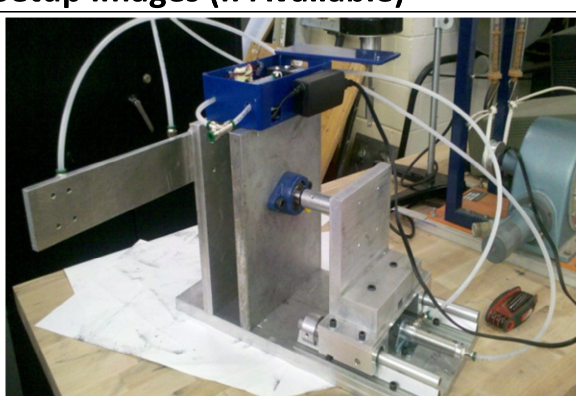
- iPhone
- Air source
- Wear Test machine

Date Performed	Beginning Time	End Time
3/28-4/4	8AM-5PM	

Results

See results in report

Setup Images (If Available)



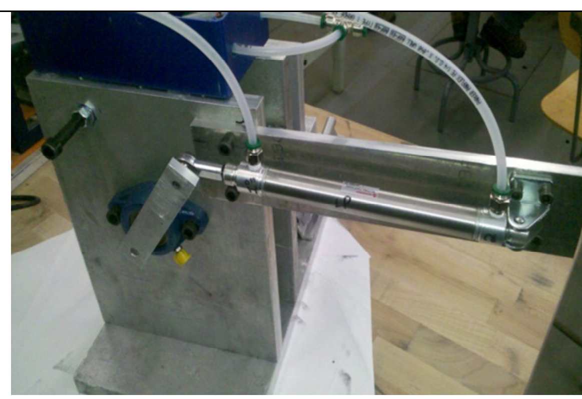


Figure 46

13.10 Compression Testing

The compression testing that was performed was to verify that the heel could withstand the weight of a person from our design specifications.(INSERT DESIGN SPEC TABLE #). These design specifications account for the weight of the 95th percentile. The weight of a women in the 95th percentile is 235 pounds. The force exerted by a person when they stand up is 5 to 6 times their body weight which would make the force exerted 6270 N.

Two design fixtures were designed to perform a test. Due to limited materials a piece of Delrin had to be hollowed out and drilled. Rather than inserting the heel and twisting it to lock it, the heel was inserted into the fixture. This will put a piece of Delrin in between the connector and the heel. This design fixture is shown in Figure 47.

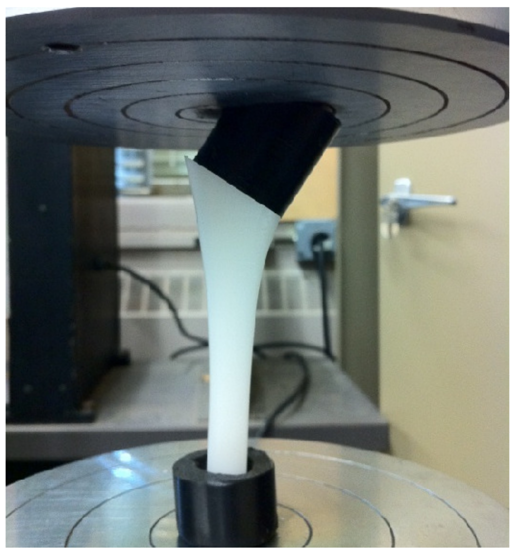


Figure 47: Design Fixture made out of thin Delrin

Another design fixture was designed out of Aluminum. The piece of aluminum was cut at 28 degrees and is shown in. This piece fits directly on the flange piece that was designed for the wear test. The 28 degree cut will allow for the heel to fit into the Instronmachine for a compression test. This test fixture is shown in Figure 48

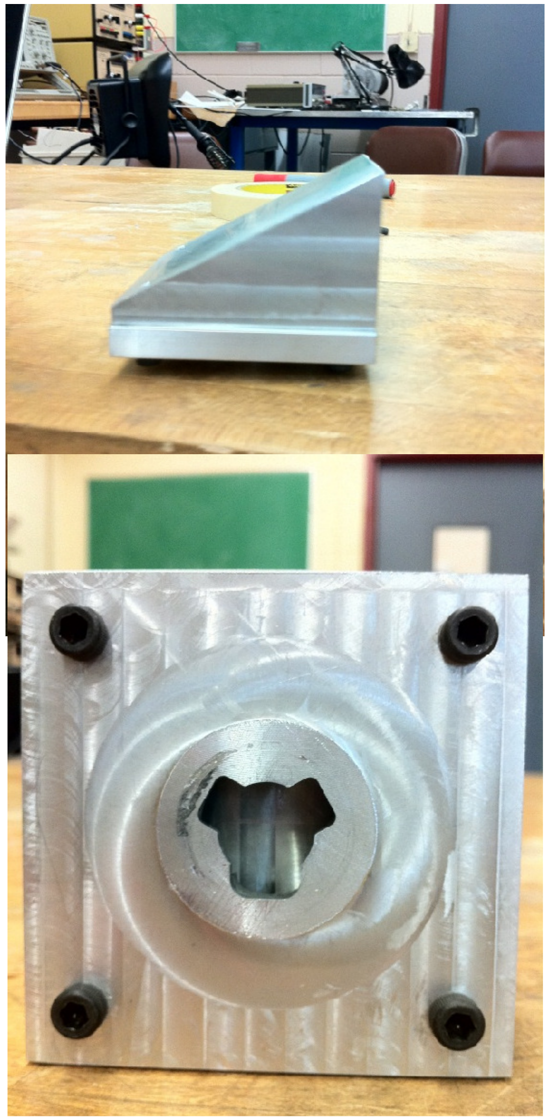


Figure 48: Side and BottomView of holding Fixture

The compression test was performed 3 times. The first test used the Delrin fixture and the Delrin failed at 1500N. The heel piece was not damaged during this test. The holder piece broke off because it was too weak and the holder was not a good representation of how the heel would actually attach to the shoe. The thickness of the connector was not the same as the final design would be.

Figure 49: Compression Test 2 and 3

The second and third compression tests were performed with the aluminum fixture and the results are shown in Table 6.This table shows the compression in mm that the instron machine experienced when the force was applied The first time this test was performed the heel was in the upright position and the second time the test was performed the heel was in the upside down position. Both times the test was performed the screw that was holding the heel in the connector broke right after the 6000N results was obtained. The connector piece was forced too far down and the screw would pop right out. The actual heel piece was not damaged and was not deformed in any manner. The data from these Tests are shown in Table 6

Test 1		**Test 2**	
Force(N)	Compression(mm)	Force(N)	Compression(mm)
1500	1	1500	1
2000	1.24	2000	1.26
2500	1.4	2500	1.41
3000	1.5	3000	1.5
3500	1.8	3500	1.78
4000	2.03	4000	2.07
4500	2.27	4500	2.31
5000	2.54	5000	2.58
5500	2.86	5500	2.9
6000	3.12	6000	3.17

Table 6: Compression vs Force Data

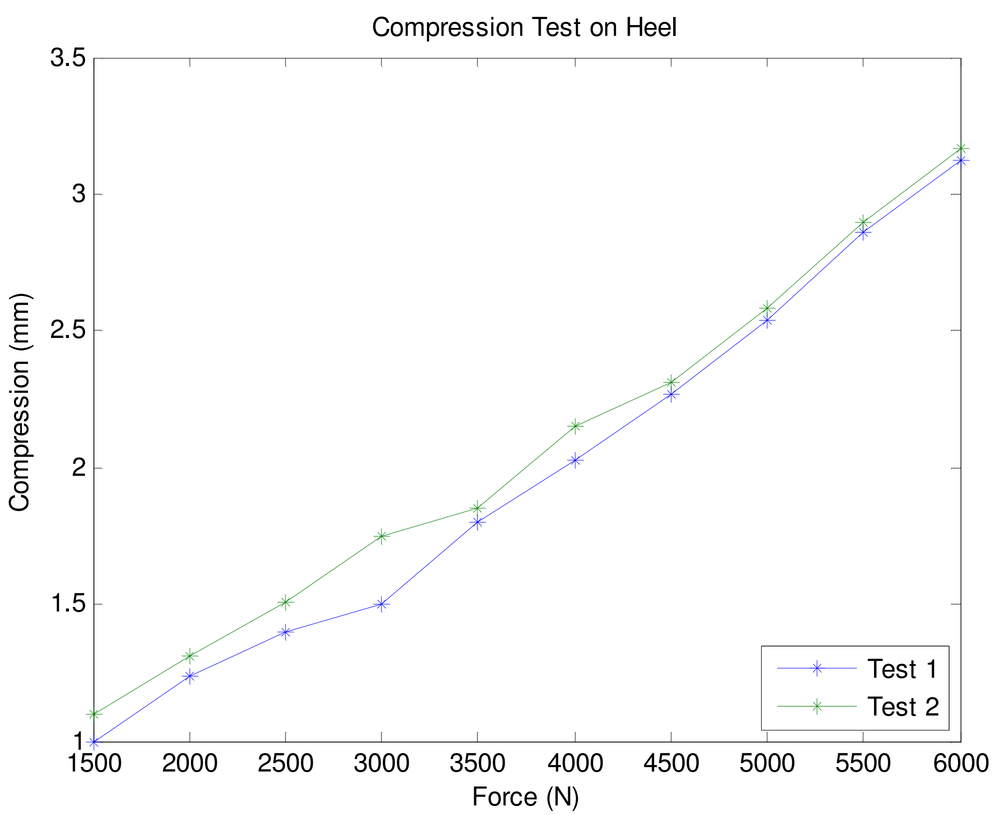


Figure 50: Heel Compression in mm vs Force in N

13.11 **Conclusions**

Looking at these results the actual heel is not a problem but the problem is the connector piece. There could be a few reasons for the results that occurred. First the screw that is used in the connector was not going down in the hole the entire. This would significantly reduce the strength of the screw because it would not have as much material to hold on to. Second when the heel piece was manufactured the square hole that the connector piece sat in was too big. This allows the connector to move and wiggle even when it was held down with a screw. If the tolerances were tightened up on these pieces the connector and the material used for the connector will be used for the heel will take more of the load

Another error that occurred during the test was that the angle that the holding fixture was cut at did not line up perfectly and keep both the fixture and the heel parallel. This is one of the reasons that during the third test the fixture was inserted upside down.This would ensure that the one of the sides was perfectly straight. This orientation was also used in order to try to perform another test because of how the screw destroyed most of the integrity of the threads after the first test.

An additional way the problem could be fixed is by changing the angle at which the connector is on the shoe. This information could be used for another redesign. If the connector is more in line with the heel of the shoe then the axial load will be transferred through more of the heel and not just the connector.

When these problems have been accounted for the heel and the connector should be able to withstand the force that was in the design specifications. The next step would be incorporating a factor of safety of around 1.2. When the factor of safety is accounted for the force the heel should withstand is around 7500N.

Test Name			
Compression Test			
Description			
A compression test with the High Heel Shoe and Connector			
Team Members Performing Test			
Nick DiFilippo	Kayla Morgan		
Design Specification(s) to be Tested			
• The heel can withstand the force exerted by a women in the 95th percentile ~6000N			
Equipment Required			
• Instron testing Machine • Heel • Instron			
Date Performed	**Beginning Time**	**End Time**	
4/27/11	10:00	11:30	
Results			
Compression Test failed with Delrin connector at 1500N. The Delrin Connector wasa not a good design and the walls were too thin. The connector failed right around 6000N with the Aluminum Tests			

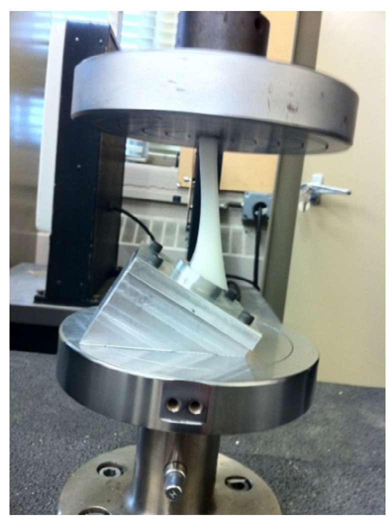


Figure 51

14 Redesign

This team went through a few rounds of redesign. The first prototype that was made of the twist and lock design showed the team that twist and lock was a good concept but that there were still many issues that needed to be worked out in order to make it a fully working design. The first design is shown in the figure below.

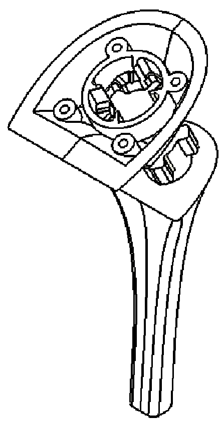


Figure 52: The original twist and lock heel design

There were two major issues with this design, the first was that the locking mechanisms did not work and the second was that the nodes were symmetrical so the heel could be twisted into the shoe in the wrong direction. The locking mechanisms in this design were too small that when the heel was first twisted into place the locking mechanism bumps broke off. In order to fix this problem the bumps were redesigned so that they took up more surface area and they were shallower, which ensured that the bumps would not break off when the heel was twisted on. The second issue with the original design, as discussed before, was that the nodes were symmetrical which allowed the heels to be twisted in the wrong direction. In order to fix this problem the team designed the node piece so that it was asymmetrical. The heel after the first redesign is shown in the figure below.

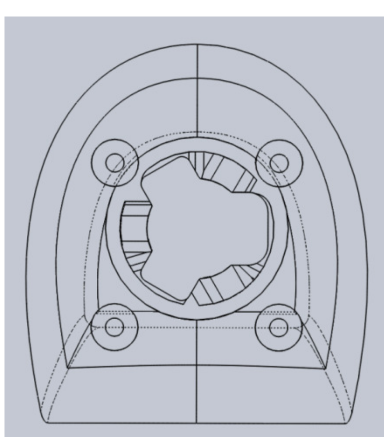
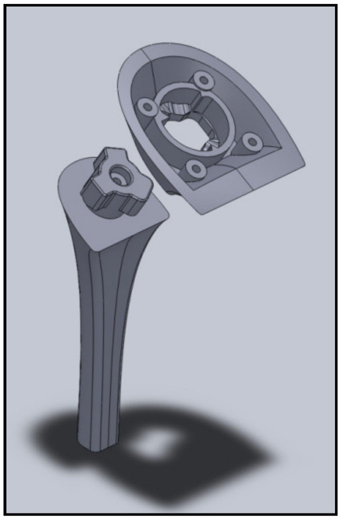


Figure 53: Picture showing how the node arrangement is asymmetrical



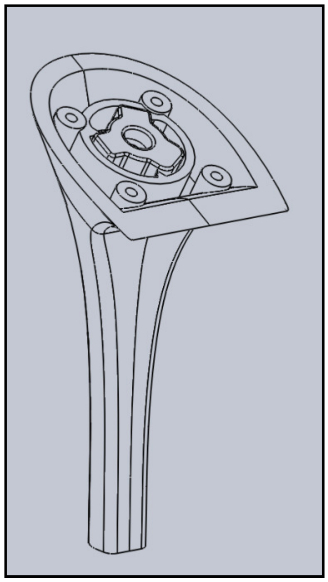


Figure 54: Picture showing the heel after the first round of redesign

Figure 55: Picture showing the heel after a round of redesign

Once the heel was redesigned in SolidWorks it was printed using the rapid prototyping machine. This model proved that the issues with the first model were fixed, the symmetry and the bumps breaking off. This model also brought up more issues that needed to be assessed. The main issue with the new model is that the heel wiggles when it is on the shoe. This was bad because it made the heel design unsafe to be worn. The model of the heel was attached to a real high heel shoe in order to make sure that the heel design could attach properly. The high heeled shoe that the team attached their heel to was from the brand 'Naturalizer' which is the brand the sponsor has requested to use. The photographs of the heels are shown below.

Figure 56: Naturalizer brand high heel with sole uplifted and heel removed so that the twist and lock heel can be attached.
Figure 57: Naturalizer brand high heel with sole uplifted

Figure 58: Naturalizer brand high heel with heel removed

Figure 59: Twist and lock heel from first round of redesign attached to an actual shoe

In order to fix this major flaw the team went through a second round of redesign. The results of the second round of redesign was to put either a compression spring or a piece of rubber in the base of the heel which would prevent the heel from wiggling. The spring did not work as planned because it would twist and bend when the heel was twisted. Although the spring did not work as planned, the rubber worked perfectly. The rubber piece in the base of the heel allowed the heel to be twisted on and off as well as stopped the heel from shaking.

15 Operation/Assembly/Repair/Safety

The operation of this project was designed to be as simple as possible. It was designed in such a way that no operator's manual is necessary for use. No safety guide, assembly manual, or repair manual is necessary. These extra booklets significantly increase the cost of the product and will take away from the sleek design of the product and designer packaging, as the packaging will be used as the storage for the extra heels.

16 Maintenance

This product requires very little maintenance outside of the usual maintenance that goes along with owning and using a pair of high heel shoes. The new design will have the detachable heels, that when damaged, can easily be replaced. Further maintenance to the actual shoe should be done by a professional, as shoes often need glues and equipment usually not found in a household. This lifetime of the connector part of the shoe is estimated to approximately 10 years of daily use, which is significantly longer than the lifetime of any shoe in existence. For the heel and heel base, Delrin (acetal) is used. Polyoxymethylene (POM), acetal, can be recycled but is usually just thrown into the landfill, as it is not used as much as other plastics. Depending on some of the glues used in the rest of the shoe, it is usually disposed of in a landfill when it no longer can be of use.

17 Additional Considerations

17.1 Environmental Impact

Figure 60: SolidWorks Sustainability Report

The following sustainability report was generated using the SolidWorks Sustainability calculator. It uses approximations that are useful to get a rough idea of the impact that this product will have on the environment. This report does not include parts like screws used in assembly and the packaging used for transportation and marketing.

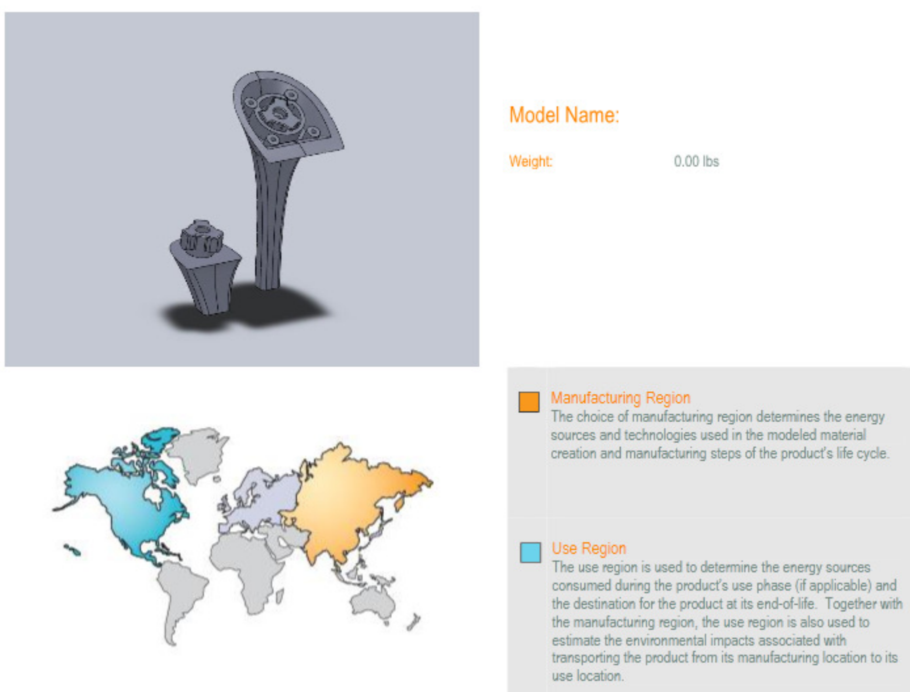


Figure 61: SolidWorks Sustainability Report 2

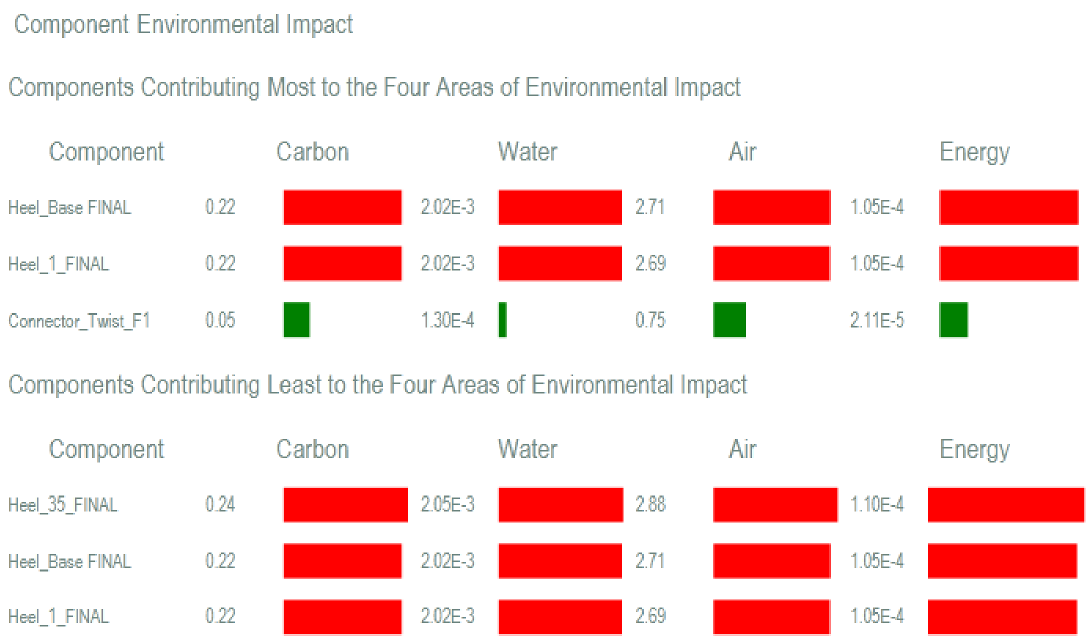


Figure 62: SolidWorks Sustainability Report 3

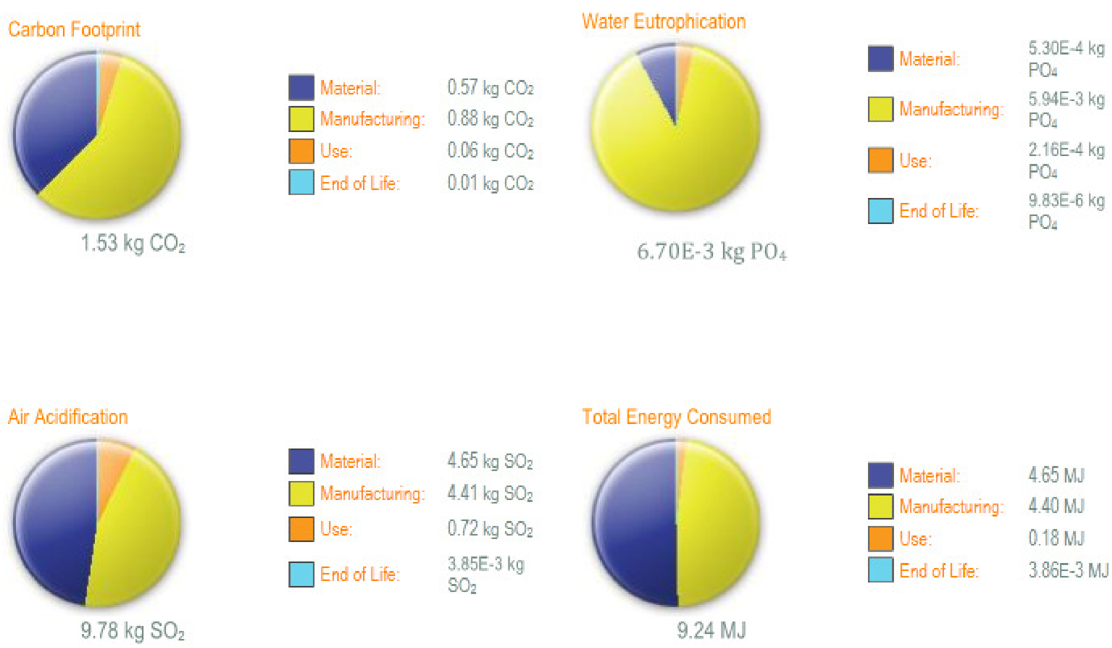


Figure 63: SolidWorks Sustainability Report 4

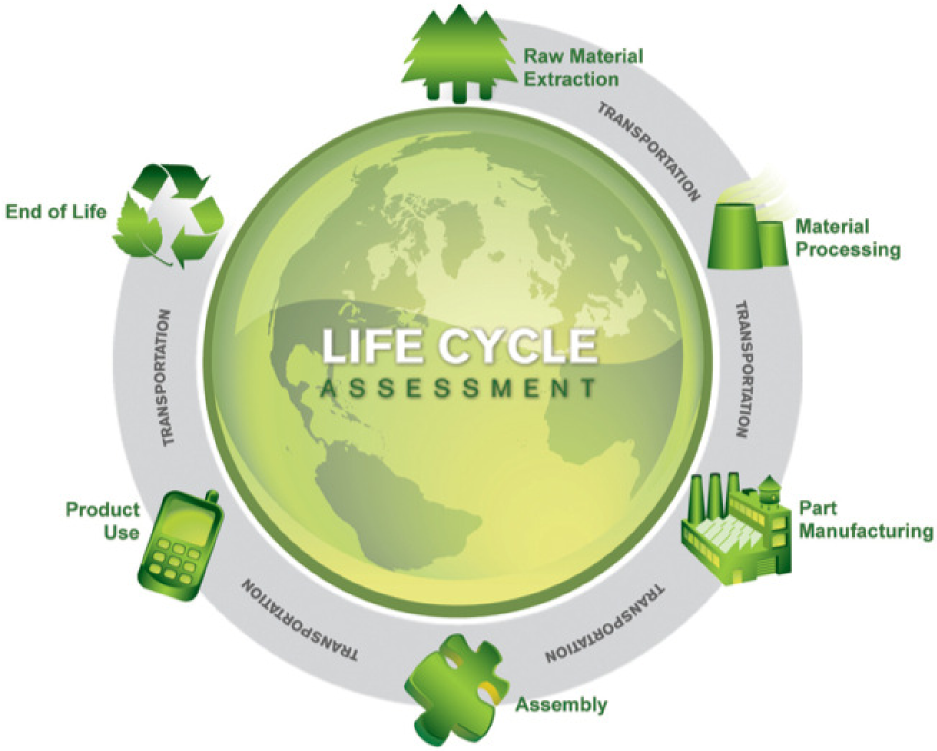
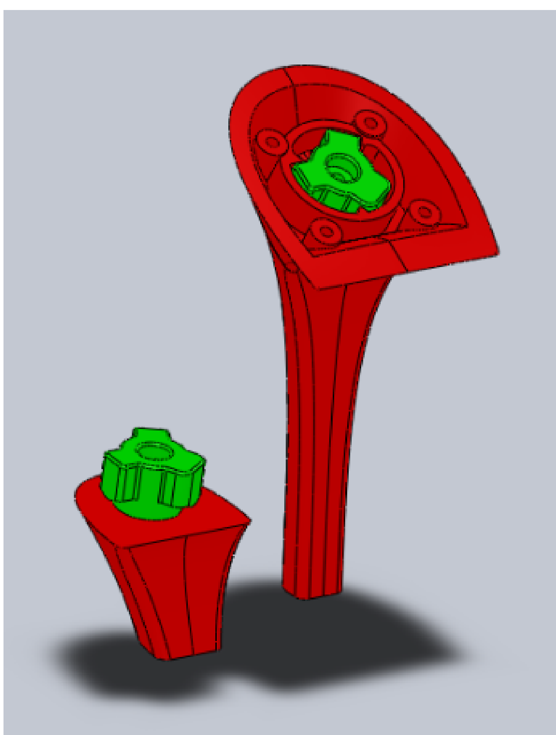


Figure 64: SolidWorks Sustainability Report 5



17.2 **Societal Impact:**

Dynamic Heels will certainly have a societal impact around the world. While women will always purchase different shoes to have different styles and colors to suit different outfits and levels of comfort, they will now be able to buy less. They can do this by purchasing one pair of Dynamic Heels to replace the standard one black strappy high heel and one black kitten heel sandal, essentially HALVING the number of shoes a woman needs in her closet or suitcase. One day, this product will go even further than changing heel heights by also being able to change heel styles. Feel like wearing a solid chunky heel for more stability and comfort at work, but want to change into a stiletto heel for drinks afterward? It will be possible to do all of this with one shoe. These shoes will be available in a variety of colors and styles, possibly making other shoes obsolete.

17.3 **Political Impact:**

One of the many hot topics in politics right now is bringing jobs back “home” to the US. Since so many things are being outsourced to other countries, including call centers, auto manufacturing facilities, televisions (despite the fact that they were invented here in the US), etc. Today, many shoe companies manufacture their products in other countries, simply to cut down on the cost for consumers. Typically high end shoes are handmade and produced in the same area as the designer, including brands like Salpy (made in the US). Having our shoes produced in the US would increase the cost of the shoes, but would create jobs for hundreds who could work on the assembly line.

17.4 **Ethical Considerations**

An ethical dilemna that could potentially effect this product is if there were any doubt in the safety of this high heel. If the testing on the high heels showed that there is potential for the heel to break and for women to get hurt, then that design should NOT be manufactured and the heel should be redesigned. It would be unethical for a product to be put out in the market when the company knows that there is a problem with the product and that it could potentially be harmful. It would be bad if Candice put a high heel out in the market that she knew might break and cause injury. If the high heel did break when some women were wearing it and those women were to sue Candice for pain and suffering money, it would look really bad that Candice knew that her product could potentially hurt people and that she decided to sell it anyways. That fact could potentially put her company out of business.

On the other hand, say that there was a design issue with the shoe that Candice did not know about. Say there was an issue that the heel would pop off in certain conditions, but that this information did not come up during testing. If Candice had know idea that the heels were defective and women wearing them started getting hurt because the heel was breaking then Candice would need to recall the shoe right away. It would be unethical for Candice to keep selling the shoe once she found out that the heel was defective. She would need to recall all the shoes and redesign her heel so that it would work properly. This example is similar to the issue with the Ford Pinto, where there was a design issue with the car that was causing harm and death to people driving them. The Ford company thought that it would be cheaper for them to simple pay for the law suits for the people that did get hurt driving their car rather than simple paying to have all the cars recalled and fixed. In the end the company not only ended up paying way more money in law suits then they would have payed to recall all the cars, they also tarnished their reputation because they chose to let people get injured rather than pay the money to recall and fix their problem.

There are other ethical issues that don't relate to the safety of the shoe, it has to deal with the legal side of the product. Candice needs to do a full patent search before she begin production of her high heel to make sure that there are no other products out there that are similar to her design. If she were to infringe on an existing patent she would have to pay a lot of fees and penalties along with legal fees because she would need a lawyer. Along with this idea Candice would need to make sure that she patents her idea right away to make sure that no one sees her design and steels her idea.

17.5 Health, Ergonomics, and Safety Considerations

Health, ergonomics and safely are key aspects to this project. High heels directly deal with ergonomics, health and safety. Safety was a main consideration when making this project because if the heel design isn't safe then women could break their ankles. The first consideration that is going to be touched upon is the safety considerations if the heel were to pop off. If the heel were to pop off when a women was wearing it then she would fall, during which she could easily sprain or break her ankle. Also, if she put her hand down to try to catch her fall she could break her arm or wrist. If the woman wearing the high heels was elderly she could break her hip if she fell. Any of these injuries would definitely be painful both physically and emotionally. Candice would be sued thousands of dollars for pain and suffering. If the heel was not designed correctly then it wouldn't be just one person who falls and breaks a bone, it would be hundreds if not more people who could potentially sue Candice. This would be a catastrophe, and Candice could potentially lose everything she has and owe thousands of dollars to people that were hurt while wearing her shoes. For this reason the heels need to be tested thoroughly before manufacturing in order to make sure that the heel will not pop off or break when being worn.

Another considerations that is important for the design of this heel is ergonomics. The ergonomics of any shoe is important in order to prevent leg and back pain, but the ergonomics of a high heeled shoe is especially important because all of the weight of the women is focused on a smaller area and high heels are harder to walk in. If the heel is not designed correctly to fit the posture of the human body then women could get severe back pain from walking around on the high heels for a long period of time. Candice has the potential for being sued for pain and suffering money from women who wear her heels and claim to have gotten severe back pain from them. If someone were to sue Candice because her high heels were causing pain, Candice would not only lose profit from her business because she would have to pain the settlement money, but she would also lose profit because it would give her business a bad name.

17.6 Globalization Considerations

There may be globalization issues that arise in the manufacturing of this product. This is because most shoes are manufactured overseas. These high heels would most likely be produces in a Asian country. Most shoes are manufactured in foreign countries because manufacturing and assembly costs are cheaper in other countries. One of the reasons they are cheaper is because they can pay workers less money in other countries and they don't need to off the same benefits that are offered in the United States. Although Candice would be able to pay less for the heels to be manufactured in the an Asian country then she would have to pay here, she would still need to pay them a fair amount. A globalization issue that may arise in Candice's situation is that United States patents don't control other countries. The Asian company that would produce Candice's high heel may decide to copy her idea and start producing their own interchangeable high heels and selling them for a lot less than Candice would be selling them for. There isn't much that Candice could do to stop them from stealing her idea and producing it themselves. For this reason Candice needs to be careful where she has her shoes manufactured.

18 Conclusions

The team successfully designed an interchangeable high heel. The high heel design meets all of the design specifications given by the sponsor. The first design specifications that the sponsor had requested were that she wanted five heel heights, a simple design, and for the heel to be able to attach without the use of tools, all of which have been met with the current design. The heel has been tested and it holds up to the rigorous compression and wear specifications. There are two locking mechanisms, which were designed to ensure that the heel does not untwist while being worn. The current heel design would be produced by injection molding and the mold would cost between $20,000 and $30,000 which allows the heel sets to be manufactured for approximately $33.00 per set. This cost would allow the sponsor to achieve her design specification of a 50% profit margin. This interchangeable high heel design is ready for manufacturing and marketing.

This design has the potential to be extremely profitable for many reasons, the most important being that there is no current high heeled shoe like this out on the market in the United States. The only high heels that are close the this design are the Camelion Heels which only allow the consumer to choose from two heels heights and they are sold overseas. The Day2Night high heels with the twist and lock heel design would come with five heels heights with a variety of different high heel styles and color. These high heels would give the consumer the freedom to create the perfect heels for any occasion without having to buy more than one pair of heels. The next steps for this heel design would be patenting the idea and then beginning manufacturing and marketing. Once the high heels were on the market this design has the potential for growth by design twist and lock heels with different styled heels. That way the consumer could choose from wearing a kitten heel to work, then skinny tall stiletto to dinner, then a chunky fashionable 2 inch heel on the way home. With different heel styles this product could really take off by allowing consumers to make high heels that match their personality, individuality, and mood. One last avenue of commercialization that this product could take is to make high heeled wedges that could have interchangeable wedge heights. The twist and lock mechanism could be used to lock the wedge heel into place but there would need to be some redesign to get the product to the manufacturing stage. In conclusion, the team successfully designed and prototyped an interchangeable high heel that met the specifications of the sponsor and is ready for manufacturing.

19 References

- Halls.md/chart/women-weight-w.htm
- Handbook of Human Factors & Ergonomics. John Wiley. Hoboken, NJ. 2006. Xxvi 1654
- Human Factors in Design & Production. John Spencer. 1971.
- "Compressive Strength Testing of Plastics." *Online Materials Information Resource - MatWeb*. 2010. Web. 10 Dec. 2010. <http://www.matweb.com/reference/compressivestrength.aspx>.
- Dieter, George Ellwood., and Linda C. Schmidt. *Engineering Design*. Fourth ed. Boston:

McGraw-Hill Higher Education, 2009. Print.

- "DSM Engineering Plastics - Technical Guide." *DSM Guide*. DSM Unlimited. Web. 10 Dec. 2010. <http://www.dsm.com/nl_NL/downloads/dep/poissons_ratio.pdf>.
- "Elastic Properties and Young's Modulus for Various Materials." *Engineering Toolbox*. Web. 10 Dec. 2010. <http://www.engineeringtoolbox.com/young-modulus-d_417.html>.
- "HUMAN PERFORMANCE CAPABILITIES." *Man-Systems Integration Standards (MSIS)*. Web. 10 Dec. 2010. <http://msis.jsc.nasa.gov/sections/section04.htm#Figure4.9.3-5>.

20 Appendices

20.1 Code for Accelerated Wear Test

```
/*  Nicks Wear Tester Rev 2
 *  by Nick DiFilippo
 *  March 4 2011
 *  This Program operates on an Arduino BlackWidow (wireless)
 *  and is attached to a relay shield which will control two solenoids that
 *  control two Pistons. One Piston Moves the slider forward and backwards.
 *  the other Piston rotates the shaft clockwise and counter clockwise.
 *  this system is set up for a linksys router using 192.168.1.125 as the server.
 *  this program is initiated by an Iphone App that starts and stops the test.
 */

#include <WiServer.h>

#define WIRELESS_MODE_INFRA   1
#define WIRELESS_MODE_ADHOC   2
int relayPin1 =  4;    // Pin that controls the Forward motion of the sliding unit.
int relayPin2 =  5;    // Pin that controls the Rotation motion of the rotating piston.

int i=0;// used for counting

// Wireless configuration parameters ----------------------------------------
unsigned char local_ip[] = {
  192,168,1,125};   // IP address of WiShield
unsigned char gateway_ip[] = {
  192,168,1,1};   // router or gateway IP address
unsigned char subnet_mask[] = {
  255,255,255,0};   // subnet mask for the local network
const prog_char ssid[] PROGMEM = {
  "WearTest"};      // max 32 bytes

unsigned char security_type = 0;   // 0 - open; 1 - WEP; 2 - WPA; 3 - WPA2

// WPA/WPA2 passphrase
const prog_char security_passphrase[] PROGMEM = {
  "1234567890"};   // max 64 characters
```

```
// WEP 128-bit keys
// sample HEX keys
prog_uchar wep_keys[] PROGMEM = {
  0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d,   // Key 0
  0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,   // Key 1
  0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,   // Key 2
  0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00   // Key 3
};

// setup the wireless mode
// infrastructure - connect to AP
// adhoc - connect to another WiFi device
unsigned char wireless_mode = WIRELESS_MODE_ADHOC;
//unsigned char wireless_mode = WIRELESS_MODE_ADHOC;

unsigned char ssid_len;
unsigned char security_passphrase_len;
// End of wireless configuration parameters ----------------------------------------


// This is our page serving function that generates web pages
boolean sendMyPage(char* URL) {

/* sets the reset pages and the pages that control the different amount of cycles the app will run
if that web page is visited then the test will start*/
  // Check if the requested URL matches "/"
  if (strcmp(URL, "/reset") == 0) {//reset so the test can be started again
    i=0;

    // set the LED on

    // Use WiServer's print and println functions to write out the page content
    WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
    WiServer.print("<table width=\"320\"><tr><td>");
    WiServer.print("<a href=\"ledon\">Goodbye I'm off! Turn me on.</a></td></tr>");
    WiServer.print("</table></body></html>");

    // URL was recognized
    return true;
  }


  if (strcmp(URL, "/five") == 0) {//5 cycle test

    WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
```

```
    WiServer.print("<table width=\"320\"><tr><td>");
    WiServer.print("<a href=\"off\">Goodbye I'm on! Turn me off.</a></td></tr>");
    WiServer.print("</table></body></html>");
    while(i<=5){
      digitalWrite(relayPin1, LOW);
      WiServer.server_task();
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      // move forward
      WiServer.server_task();
      digitalWrite(relayPin2,HIGH);
      delay(1000);
      WiServer.server_task();
      // move  CW
      digitalWrite(relayPin1,HIGH);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move CCW
      digitalWrite(relayPin1,LOW);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move back
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // Use WiServer's print and println functions to write out t\he page content
      // URL was recognized
      i=i++;
      WiServer.server_task();
      // if(i==11) break;
    }
    return true;
  }

  if (strcmp(URL, "/ten") == 0) {//ten cycle test

    WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
    WiServer.print("<table width=\"320\"><tr><td>");
    WiServer.print("<a href=\"ledoff\">Goodbye I'm on! Turn me off.</a></td></tr>");
    WiServer.print("</table></body></html>");
    while(i<=10){
      digitalWrite(relayPin1, LOW);
      WiServer.server_task();
```

```
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      // move forward
      WiServer.server_task();
      digitalWrite(relayPin2,HIGH);
      delay(1000);
      WiServer.server_task();
      // move  CW
      digitalWrite(relayPin1,HIGH);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move CCW
      digitalWrite(relayPin1,LOW);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move back
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // Use WiServer's print and println functions to write out t\he page content
      // URL was recognized
      i=i++;
      WiServer.server_task();
      // if(i==11) break;
    }
    return true;
  }
    if (strcmp(URL, "/hundred") == 0) {//onoe hundred cycle test
    WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
    WiServer.print("<table width=\"320\"><tr><td>");
    WiServer.print("<a href=\"ledoff\">Goodbye I'm on! Turn me off.</a></td></tr>");
    WiServer.print("</table></body></html>");
    while(i<=100){
      digitalWrite(relayPin1, LOW);
      WiServer.server_task();
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      // move forward
      WiServer.server_task();
      digitalWrite(relayPin2,HIGH);
      delay(1000);
      WiServer.server_task();
```

```
      // move  CW
      digitalWrite(relayPin1,HIGH);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move CCW
      digitalWrite(relayPin1,LOW);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move back
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // Use WiServer's print and println functions to write out t\he page content
      // URL was recognized
      i=i++;
      WiServer.server_task();
      // if(i==11) break;
    }
    return true;
  }
    if (strcmp(URL, "/twohundred") == 0) {//two hundred cyce test

    WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
    WiServer.print("<table width=\"320\"><tr><td>");
    WiServer.print("<a href=\"ledoff\">Goodbye I'm on! Turn me off.</a></td></tr>");
    WiServer.print("</table></body></html>");
    while(i<=200){
      digitalWrite(relayPin1, LOW);
      WiServer.server_task();
      digitalWrite(relayPin2,LOW);
      WiServer.server_task();
      delay(1000);
      // move forward
      WiServer.server_task();
      digitalWrite(relayPin2,HIGH);
      delay(1000);
      WiServer.server_task();
      // move  CW
      digitalWrite(relayPin1,HIGH);
      WiServer.server_task();
      delay(1000);
      WiServer.server_task();
      // move CCW
      digitalWrite(relayPin1,LOW);
```

```
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // move back
    digitalWrite(relayPin2,LOW);
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // Use WiServer's print and println functions to write out t\he page content
    // URL was recognized
    i=i++;
    WiServer.server_task();
    // if(i==11) break;
   }
   return true;
  }

   if (strcmp(URL, "/fivehundred") == 0) {//five hundred cycle test
   WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
   WiServer.print("<table width=\"320\"><tr><td>");
   WiServer.print("<a href=\"ledoff\">Goodbye I'm on! Turn me off.</a></td></tr>");
   WiServer.print("</table></body></html>");
   while(i<=500){
    digitalWrite(relayPin1, LOW);
    WiServer.server_task();
    digitalWrite(relayPin2,LOW);
    WiServer.server_task();
    delay(1000);
    // move forward
    WiServer.server_task();
    digitalWrite(relayPin2,HIGH);
    delay(1000);
    WiServer.server_task();
    // move  CW
    digitalWrite(relayPin1,HIGH);
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // move CCW
    digitalWrite(relayPin1,LOW);
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // move back
    digitalWrite(relayPin2,LOW);
    WiServer.server_task();
    delay(1000);
```

```
    WiServer.server_task();
    // Use WiServer's print and println functions to write out t\he page content
    // URL was recognized
    i=i++;
    WiServer.server_task();
    // if(i==11) break;
   }
   return true;
  }
    if (strcmp(URL, "/thousand") == 0) {//one thousand cycle test

   WiServer.print("<html><body><meta name=\"viewport\" content=\"width=device-width, user-
scalable=no\" />");
   WiServer.print("<table width=\"320\"><tr><td>");
   WiServer.print("<a href=\"ledoff\">Goodbye I'm on! Turn me off.</a></td></tr>");
   WiServer.print("</table></body></html>");
   while(i<=1000){
    digitalWrite(relayPin1, LOW);
    WiServer.server_task();
    digitalWrite(relayPin2,LOW);
    WiServer.server_task();
    delay(1000);
    // move forward
    WiServer.server_task();
    digitalWrite(relayPin2,HIGH);
    delay(1000);
    WiServer.server_task();
    // move  CW
    digitalWrite(relayPin1,HIGH);
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // move CCW
    digitalWrite(relayPin1,LOW);
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // move back
    digitalWrite(relayPin2,LOW);
    WiServer.server_task();
    delay(1000);
    WiServer.server_task();
    // Use WiServer's print and println functions to write out t\he page content
    // URL was recognized
    i=i++;
    WiServer.server_task();
    // if(i==11) break;
   }
```

```
    return true;
  }

  // URL not found
  Serial.println("error");
  WiServer.print("<html>");
  WiServer.print("No such page!");
  WiServer.print("</html>");
  return false;
}
void setup() {
  // initialize the digital pin as an output:
  pinMode(relayPin1, OUTPUT);   // initialize the digital pin 4 as an output:
  pinMode(relayPin2, OUTPUT);   // initialize the digital pin 5 as an output:
  pinMode(relayPin6, OUTPUT);   // initialize the digital pin 6 as an output:
  pinMode(relayPin7, OUTPUT);


  // Initialize WiServer and have it use the sendMyPage function to serve pages
  WiServer.init(sendMyPage);

  // Enable Serial output and ask WiServer to generate log messages (optional)
  Serial.begin(57600);
  WiServer.enableVerboseMode(true);
}

void loop(){

  // Run WiServer
  WiServer.server_task();

  delay(10);
}
```