

Crutch Redesign

ME 4041 Final Project

Group 5

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PROBLEM STATEMENT:

Typical crutches are used on a daily basis for those hindered by leg injuries. Their design involves simple supports placed under the arms of the user allowing for the injured leg to be suspended in the air. These crutches are uncomfortable and tiresome on the user. The goal of this project was to redesign typical crutches in a manner that creates more comfortability and a more fluid motion of operation.

PROJECT OVERVIEW AND MOTIVATION:

The crutch designed is a hands-free prosthetic type crutch. Figure 1 shows an overall view of the design.

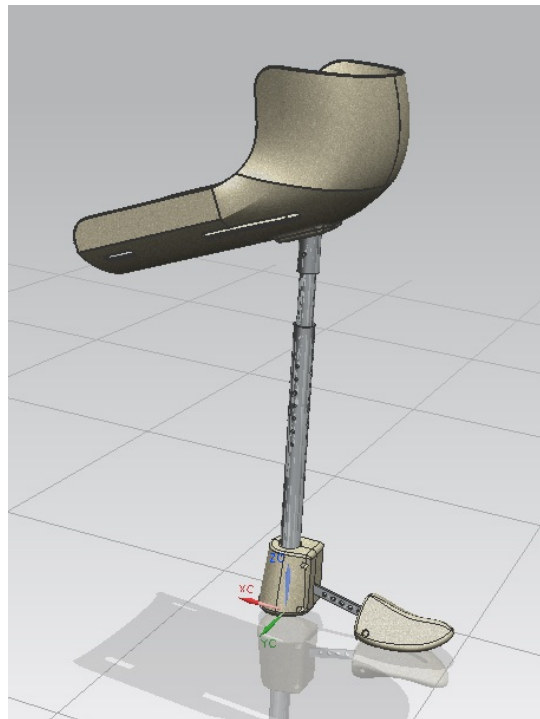


Figure 1. Overall View

This crutch was designed to interface with the user's leg at the knee while the lower is in a bent back position. The crutch design features a spring damping system to reduce impact on the user. In addition, the crutch was designed to have padding placed at the user interface to further increase comfort and reduce impact. The foot of the crutch was designed to sit inside of the user's shoe. This feature provides the user with the same traction and footing as if he or she was walking normally. The crutch also features a height size adjustment that allows for users between 5'2" and 6'2" to use this crutch. In addition, the design allows for a quick release of the leg portion of the crutch. This feature will come in handy when the user is sitting at a desk, in a car, or other confined space. By having the quick release the user is able to easily remove any part of the crutch that may interfere with the surrounds for the brief period the user is in that particular position. When ready to walk again, the user simply reattach the bottom section and never has to undo or retighten the straps.

A majority of the users of crutches complain about various comfort and mobility issues. These issues were able to be reduced or eliminated with this design. This design could also be used in a lease program through hospitals or rehabilitation facilities. Due to the adaptability and simplicity of this design, this crutch could be used many times over easily being cleaned and refurbished between users.

SUBASSEMBLIES:

FOOT:

The foot subassembly consists of the toe, toe bar, heel, and spring. The entire foot subassembly was designed to be inserted into the user's shoe when in use. Figure 1a shows the foot subassembly as a solid as well as a cross section view.

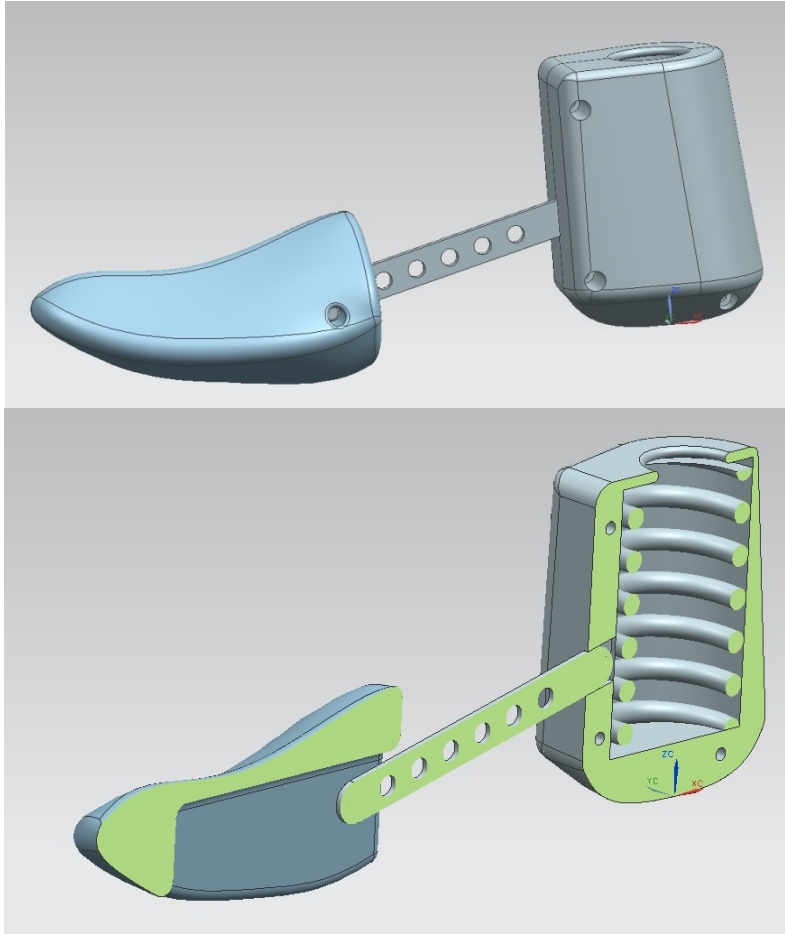


Figure 1a. Foot Subassembly

SHIN:

The shin subassembly consists of the spring plate, bottom pipe, top pipe, and quick pin. The spring plate is connected to the bottom of the bottom pipe. The two pipes are telescoping and connect using the quick pin. Figure 2a shows the shin subassembly.

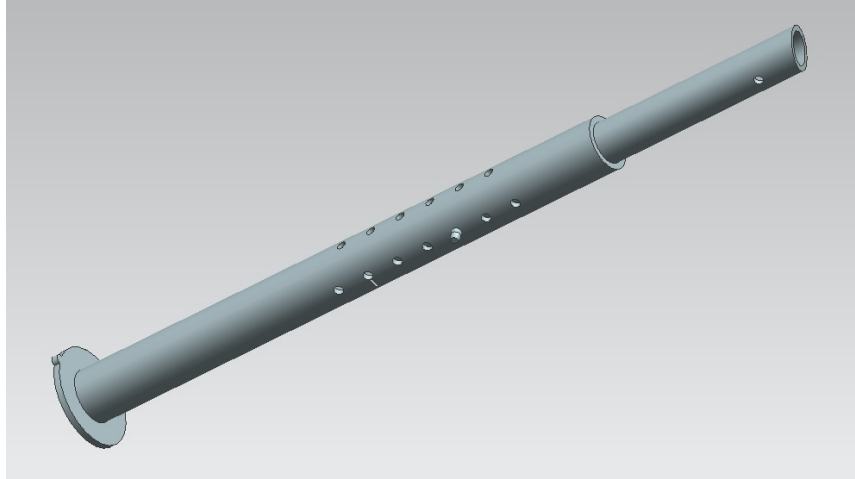


Figure 2a. Shin Subassembly

KNEE INTERFACE:

The knee interface subassembly consists of the knee shin interface, knee holder, and quick pin. The knee holder connects to the knee shin interface using four bolts. The knee shin interface connects to the shin subassembly by sliding over the top pipe and inserting a second quick pin. Figure 3a shows the knee interface subassembly.

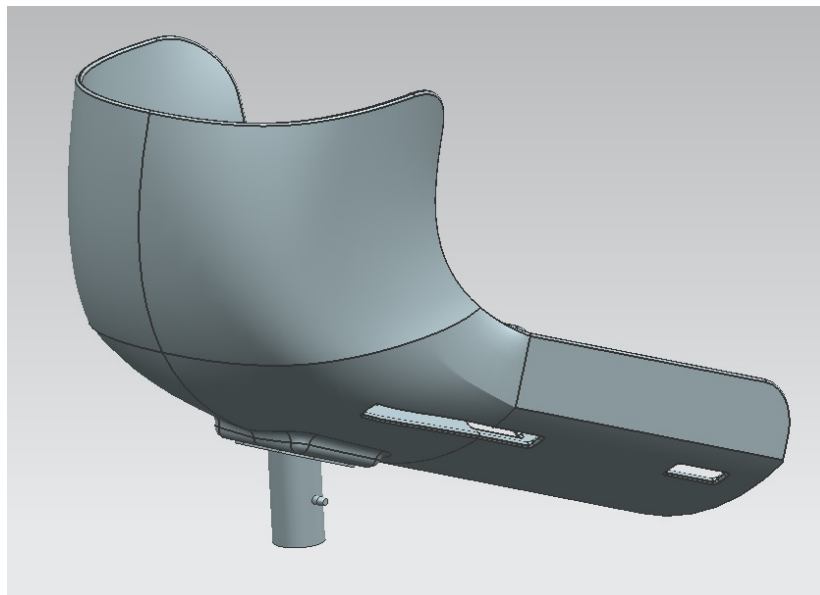


Figure 3a. Knee Interface Subassembly

PART MODELING:

TOE:

The toe part was created to sit inside of the user's shoe. To begin the modeling process, several splines were created to outline the general shape. Figure 1b shows the first splines.

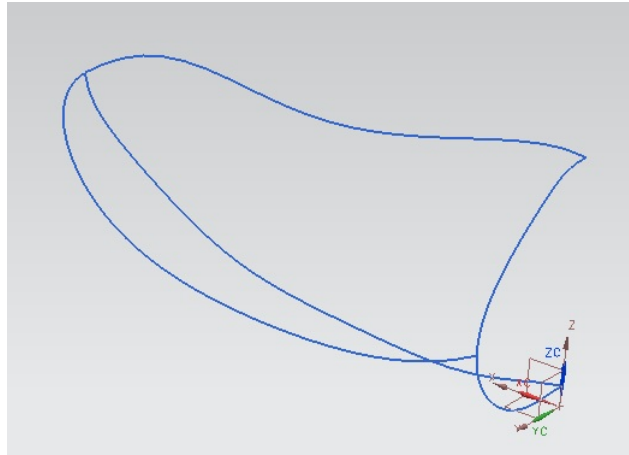


Figure 1b. Toe Splines

These splines were then mirrored across the XZ plane to create a complete outline of the desired shape. Figure 2b shows the completed splines.

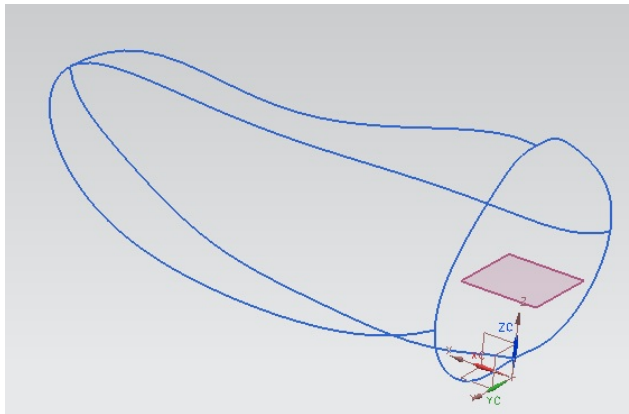


Figure 2b. Completed Splines

Based on these curves, a surface was created. The N-sided surface command was used to create four separate sheets for the top and bottom surfaces on the toe. Figure 3b shows the surfaces created using the N-sided surface command.

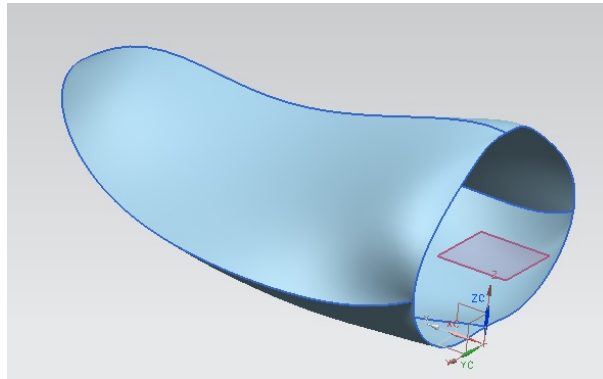


Figure 3b. N-sided Surfaces

At this point, all surfaces were created except for the back. The bounded plane feature was used to create the back surface and enclose the shape. Figure 4b shows the completed sheet body.

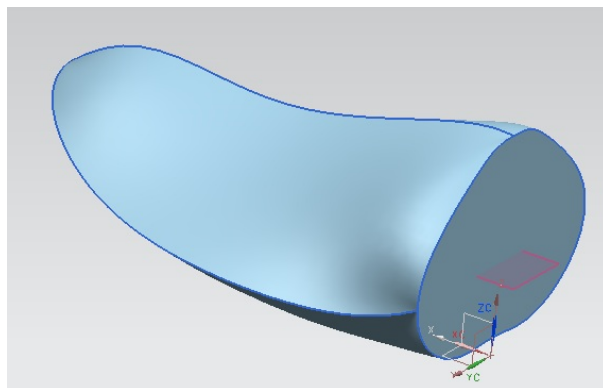


Figure 4b. Sheet Body

To convert the sheet body to a solid body, all of the surfaces were sewed together using the sew command. Once the solid body was created, all edges were rounded using the edge blend feature. Figure 5b shows the blended solid body.

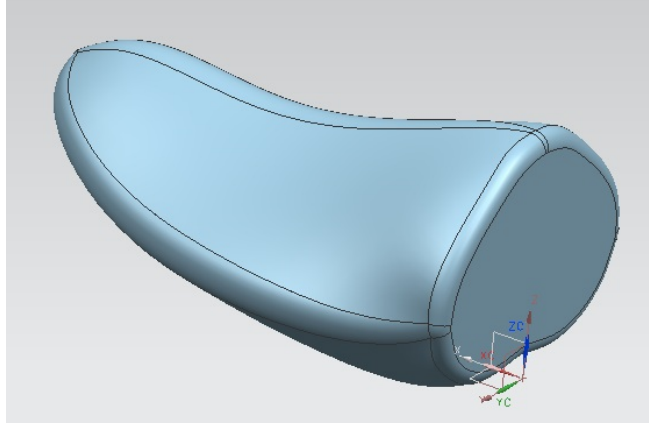


Figure 5b. Blended Solid Body

The next in the modeling process was to create the channel for the size adjust bar and hole for the pin. The pin hole was created by extruding and subtracting a circle from the mid-plane through both sides. The channel was created by subtracting a rectangular extrusion from the back surface towards the front of the toe. Both features are shown in Figure 6b.

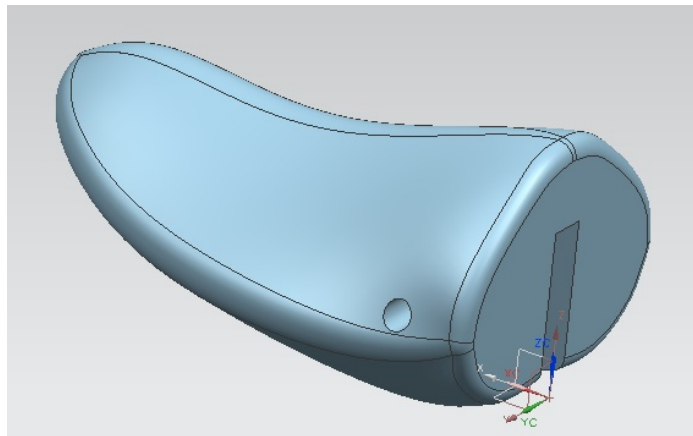


Figure 6b. Pin and Size Adjust Bar Cutouts

The resulting edges from both the pin hole and size adjust bar cutout were all rounded using the edge blend feature. The finalized toe part is shown in Figure 7b.

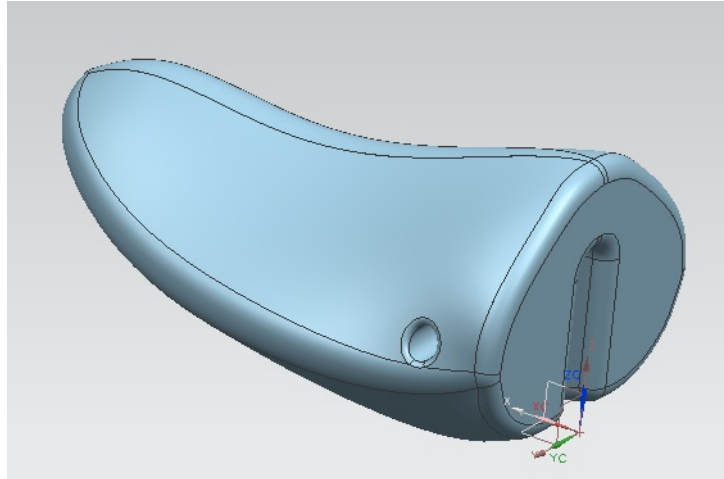


Figure 7b. Finalized Toe

TOE BAR:

A toe bar was created to connect the heel to the toe of the crutch. The toe bar is adjustable to accommodate small female shoes and larger male shoes. Extruding a 4.312 x .5 inch rectangular cross section for .125 inches created the initial toe bar. Seven .25-inch holes were then patterned and extruded through the rectangular bar at .5 inches apart. Figure 8b shows the rectangular bar and seven holes in the toe bar.

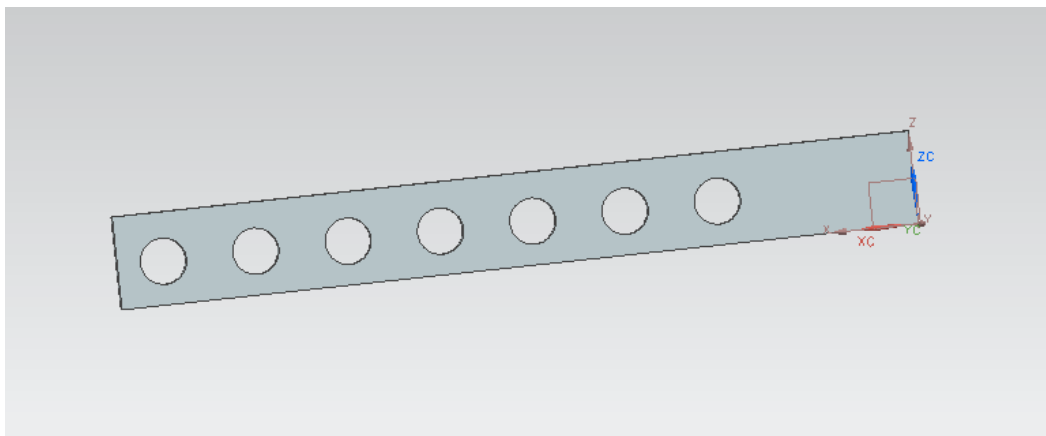


Figure 8b. Initial Toe Bar Model.

Next, a .25-inch radius edge blend was used to round off one end of the toe bar. Figure 9b shows the edge blend of the toe bar.

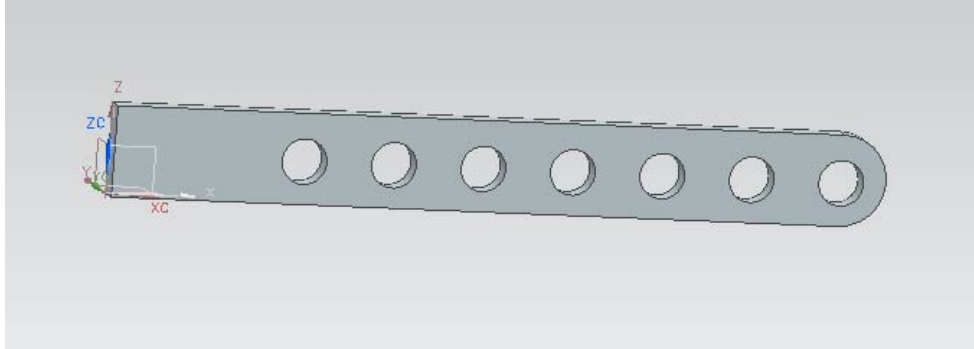


Figure 9b. Toe Bar Rounded.

Finally, another .25 hole was added to the other end of the toe bar and the corners were also rounded using a .25-inch radius edge blend. The hole at the end of the bar would connect to the toe using a simple pin. Figure 10b shows the final model of the toe bar.

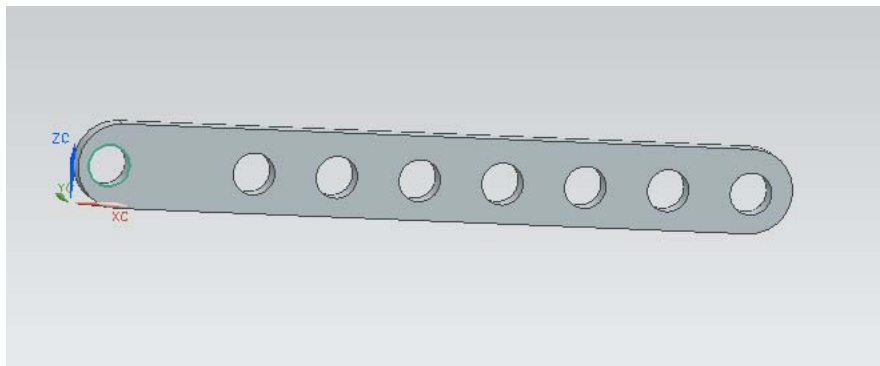


Figure 10b. Final Model of Toe Bar.

HEEL:

The heel was designed to house the spring used for dampening the ground reaction forces on the crutch as well as providing support when placed inside the user's shoe. The heel is split in half housing the spring and spring plate inside and then the two halves are bolted together. To

begin modeling this part the heel of a human is traced on graph paper generating points to create splines. The splines create a wire frame for the bottom of the heel. Using the n-sided surface command a surface is wrapped around the wire frame. These steps are seen in Figure 11b.

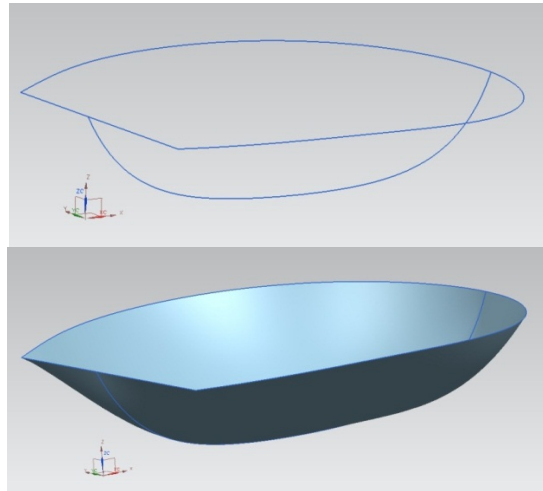


Figure 11b. Wire Frame and Surface of Bottom Heel

Next a datum plane is added at the designed height of the heel. On this plane the top of the heel is sketched using a simple circle and some tangent lines. The through curves command is used to loft from the top sketch of the heel to the bottom surface of the heel seen in Figure 12b.

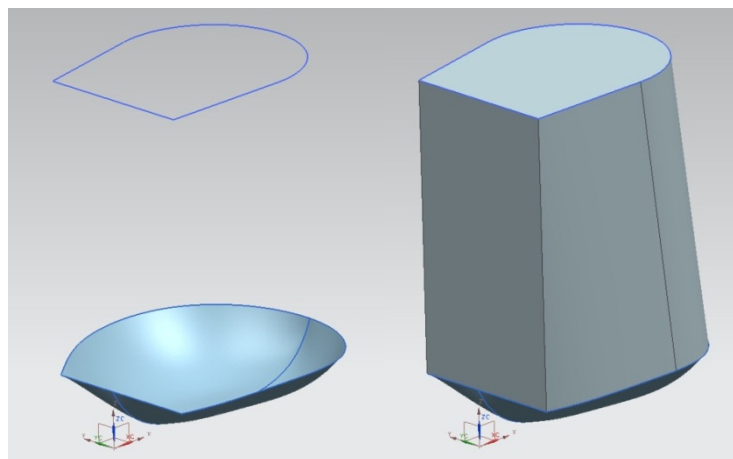


Figure 12b. Top Sketch of Heel and Lofting

Next a counter-bored hole is cut in the top of the heel. This allows the spring to sit inside the heel and the spring plate that sits on top of it is locked inside the heel. On the larger hole cut out for the spring a channel is cut into it as well for the locator tab of the spring plate. This was done with an extrusion command. Edge blends are then applied to the edges of the heel to smooth the outer surface of the heel seen in Figure 13b.

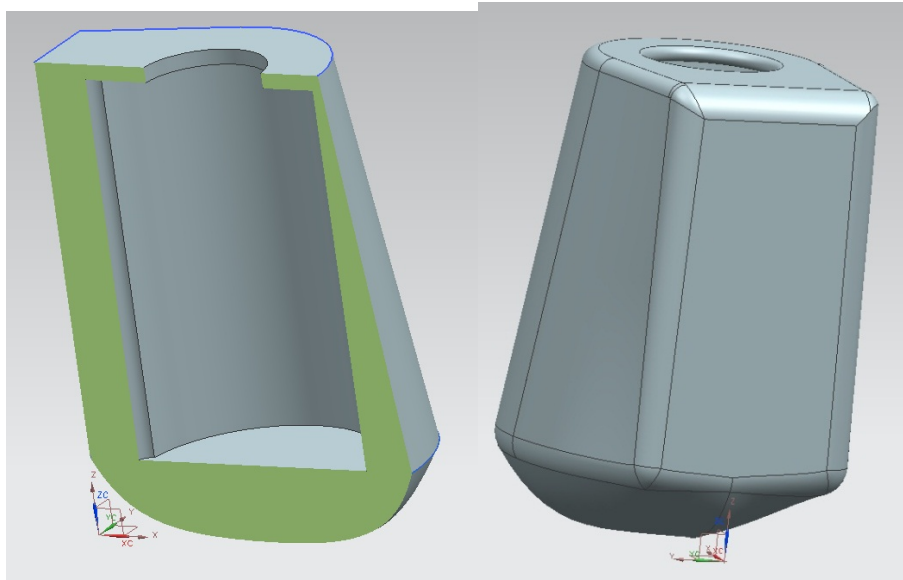


Figure 13b. Cross-Section of the Heel and Edge Blends Applied

To assemble the spring inside the heel it must be cut into two pieces. This was done by using a split body command with the xz plane as the cutting plane. Counter-bored holes are placed and the edges of the heel halves to bolt them together. One half has holes cut as the shape of nuts to allow the user to only have to use a screwdriver on the other end. This was done with extrusion commands seen in Figure 14b.

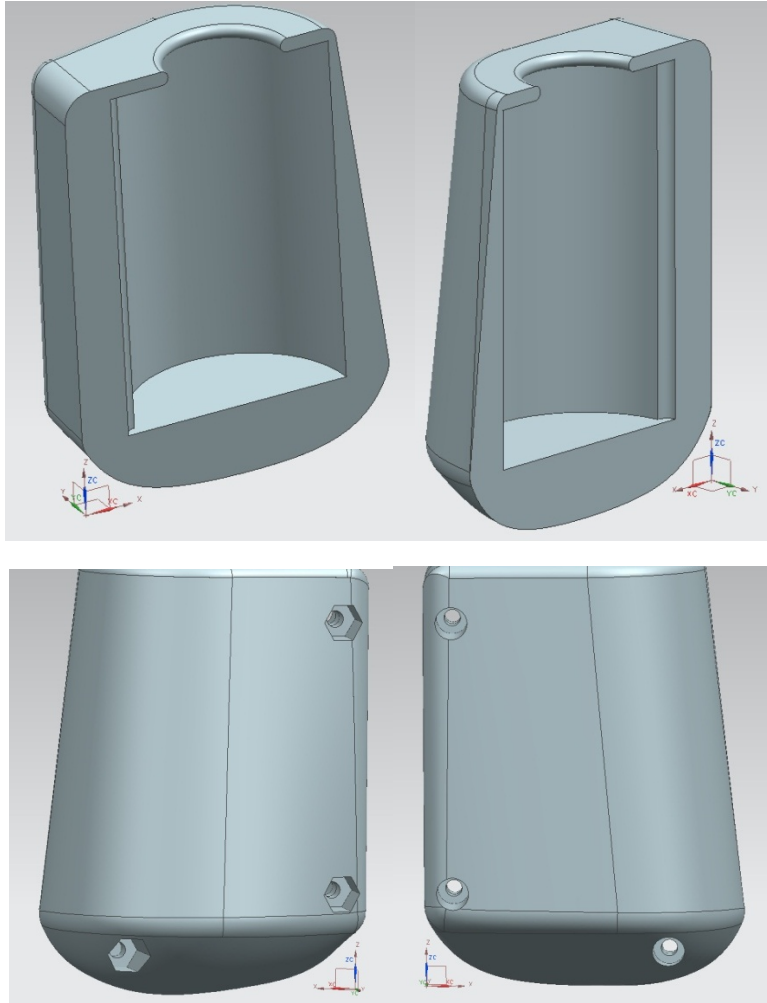


Figure 14b. Two Halves of the Heel and Nut and Bolt Holes

The toe bar connecting the heel to the toe must connect with a pin. This pin was cut into the joints of the two halves of the heel. This was done using extrusion commands seen in Figure 15b.

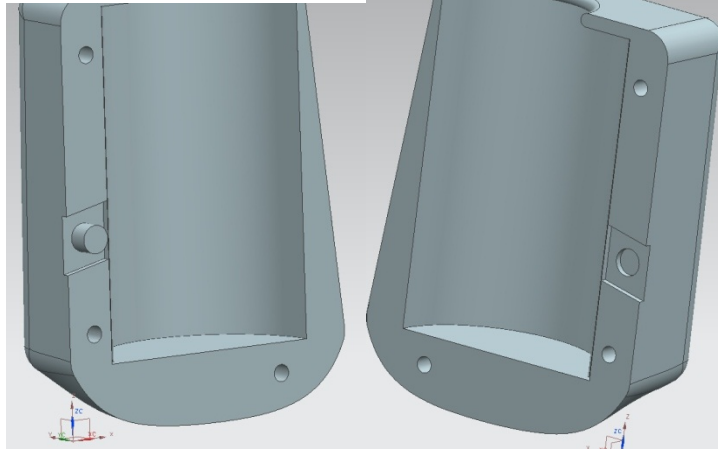


Figure 15b. Pin Cut into Heel for Toe Bar

Now the heel is assembled together. It is one part with two separate bodies that fit together. The final heel assembled is seen in Figure 16b.

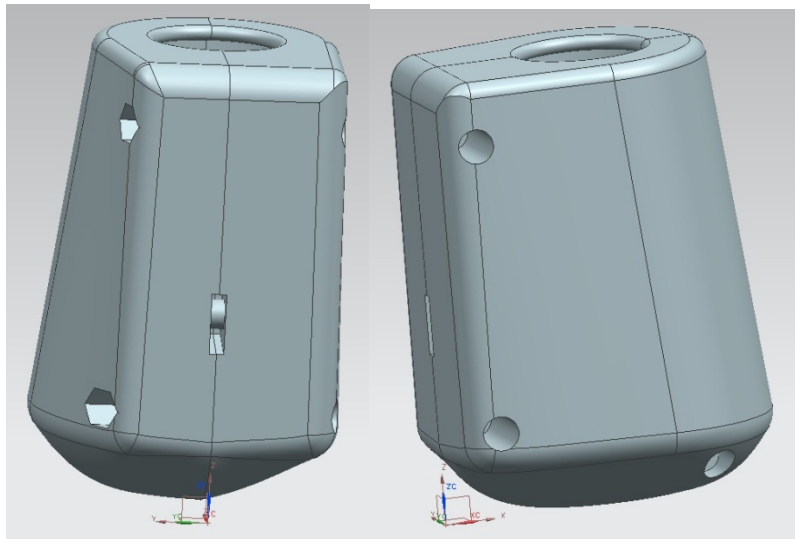


Figure 16b. Final Heel Assembled Together

SPRING:

The spring is located inside of the heel part and serves to absorb shock when the user is walking. The modeling process is shown in Figure 17b.

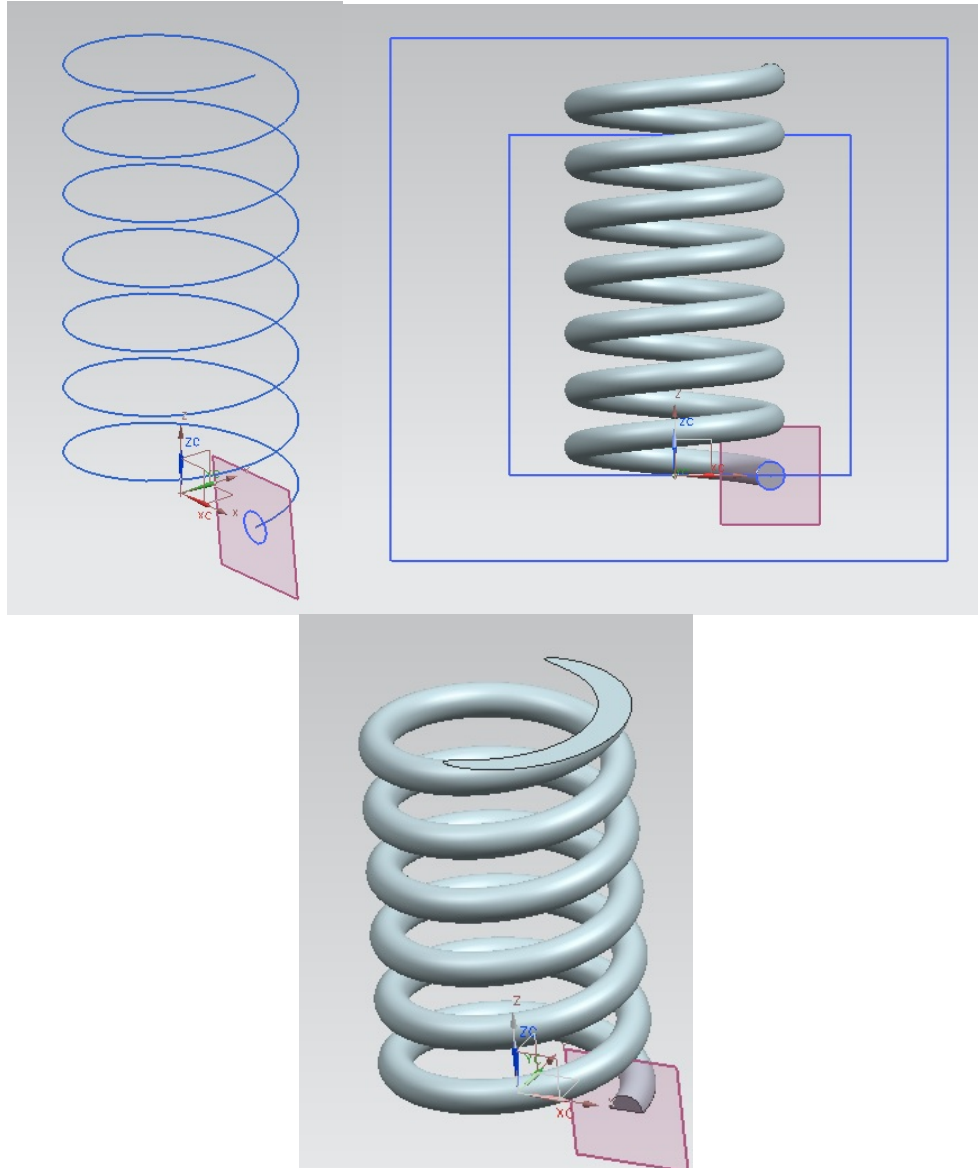


Figure 17b. Spring Modeling Process

The first step to creating the spring was creating the helical curve. Using the helix command, the curve was created based off of an existing spring. A plane was then created normal to the end of the helix where a circle was drawn. This circle was used as the profile in the sweep command to create the solid geometry. The second picture in the figure shows the completed sweep. An extrude was then used to cut the spring to length and create the flats at the top and bottom of the

spring. The second picture also shows the sketch used for the extrude. The final picture shows the completed model of the spring.

SPRING PLATE:

The spring plate was created using a basic extrude. A circle was created as the main body in the sketch. The locator tab was created by making a smaller circle on the quadrant point of the larger circle. These two circles were then trimmed to create the final profile.

BOTTOM OUTER SHIN PIPE:

The bottom outer shin pipe was created using two simple extrudes of 1.05 and .82 inch diameters. The circular sketches were then extruded to 11.875 inches and can be seen in Figure 18b.

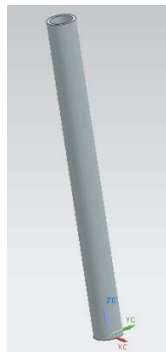


Figure 18b. Bottom Outer Shin Pipe Extrude.

The next step of the bottom outer shin pipe was to create adjustment holes so that the crutch could accommodate people heights from 5'2" to 6'2" feet tall. Patterning a single-.188-inch hole up one side of the shaft created the adjustment holes. The holes were separated by .31 inches. Figure 19b shows the sketch and pattern of the holes.

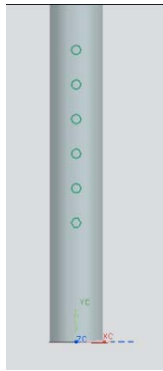


Figure 19b. Sketch and Pattern of Adjustment Holes.

The holes were then rotated by 90 degrees to the other side of the pipe and lowered to create two columns of height adjustments. The two columns allowed the crutch to accommodate users between 5'2 and 6'2 feet. The final model of the bottom outer shin pipe can be seen in figure 20b below.



Figure 20b. Bottom Outer Shin Pipe Final.

INNER SHIN PIPE:

The inner shin pipe was created using two extrudes. The outer diameter of the pipe was .82 inches whereas the inner diameter of the pipe was .622. The pipe was extruded to 12.125 inches long. Figure 21b shows the extrusion of the pipe.

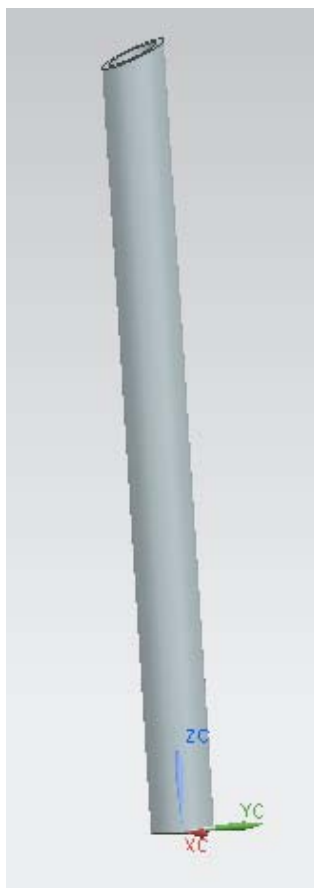


Figure 21b. Inner Shin Extrude.

The top of the inner shin needed to be cut at a 20 degree angle to attach to the knee interface section of the crutch. To do this a subtraction extrusion was used. The extrusion profile was drawn on a datum plane at the top of the inner shin pipe and then extruded from -1 to 1. Figure 22b shows the profile of the subtraction extrusion at the top of the inner shin pipe and Figure 23b shows the extrusion block used to cut the top of the inner shin pipe.

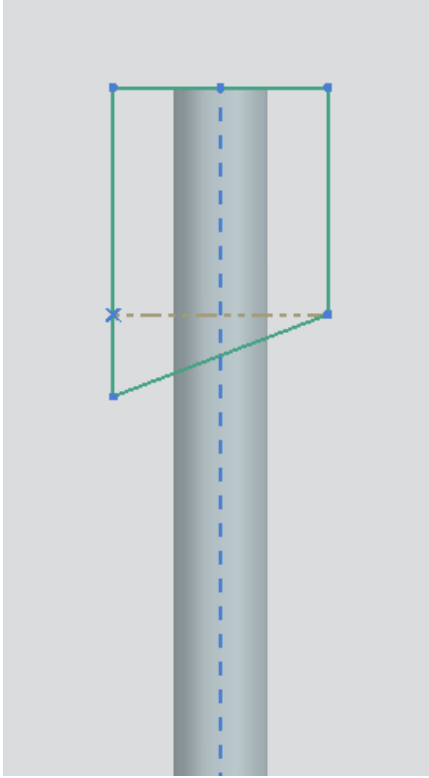


Figure 22b. Extrusion Profile.

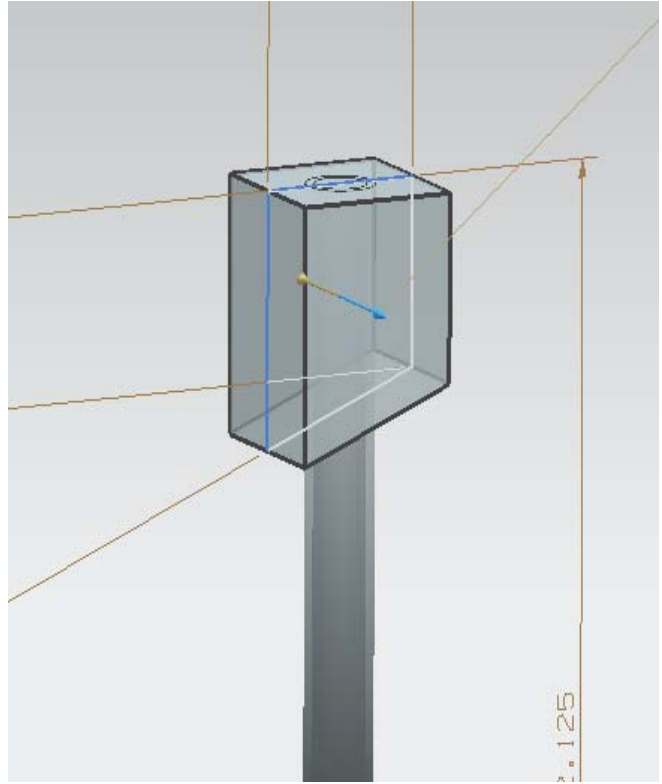


Figure 23b. Extruded Block

After the top of the shin pipe was cut four .188 inch holes were added to the bottom of the inner shin pipe to be used for the adjustment holes. The four holes were created using a simple subtraction extruded and then rotating them around the pipe as necessary. Figure 24b shows the final model of the aluminum inner shin pipe.

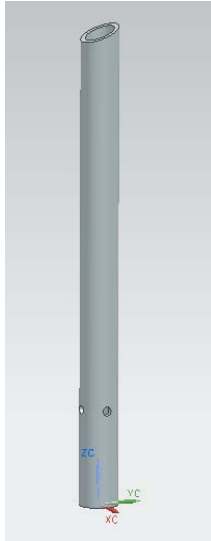


Figure 24b. Inner Shin Pipe.

QUICK PIN:

A quick pin was created to be used for the adjustment holes on the shin of the crutch. The pin was created by extruding a .188 inch diameter rod. The rod was then extruded to 2.3 inches. Figure 25b shows the pin rod.

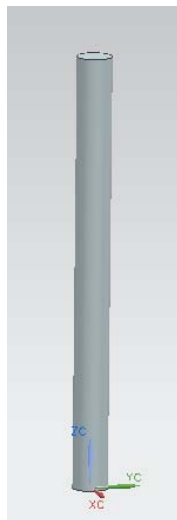


Figure 25b. Pin Extrude.

The pin was then chamfered to make the insertion of the pin into the adjustment holes easier on the user. The chamfer used was .025 inches long at an 80 degree radius. Figure 26b shows the chamfered pin.



Figure 26b. Chamfered Pin.

The final step of the pin was to add a hole at one end and a small stopping ball bearing at the other end. The hole at the non-chamfered end would allow for a key ring to be placed in it so the pin does not dislodge during the use of the crutch. The stopping ball bearing at the other end would allow the pin to be pushed through with enough force but would not come out when the crutch was in use. The hole and the bearing were both made using extrusions. Figure 27b shows the final model of the steel quick pin.



Figure 27b. Final Quick Pin Model.

KNEE/SHIN INTERFACE:

The knee/shin interface was first created by making a pipe with an inner diameter of .82 inches, and an outer diameter of 1.05 inches. The inner diameter of the pipe is just big enough to fit the outer diameter of the inner shin part described under the section “Inner Shin Pipe”. The pipe was extruded to a length of 2.15 inches. The pipe was also cut to a 20-degree angle for alignment purposes and to attach the knee/shin interface to the knee portion of the crutch. To cut the 20 degree top, a triangular sketch was drawn on a datum plane in the middle of the pipe and then a subtracted “through all” to cut away the pipe. Figure 28b shows the pipe cut at the 20-degree angle.

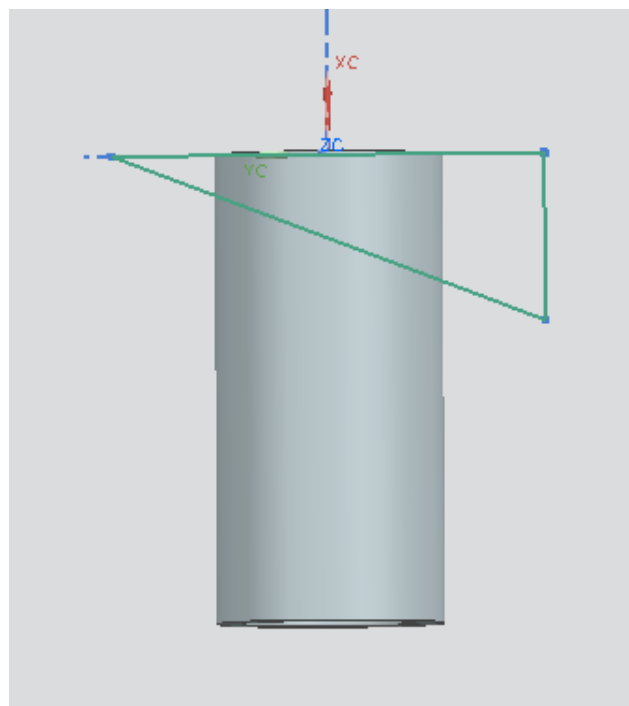


Figure 28b. Sketch of 20-degree Cut.

A plate was then added to the top of the cut pipe. The plate will be welded to the pipe that it sits on. Creating a datum plane on the top of the angled cut and extruding a 2x2 inch square created

the plate. The plate was extruded to a .0625 inch thickness. Figure 29b shows the sketch of the plate on top of the angled pipe.

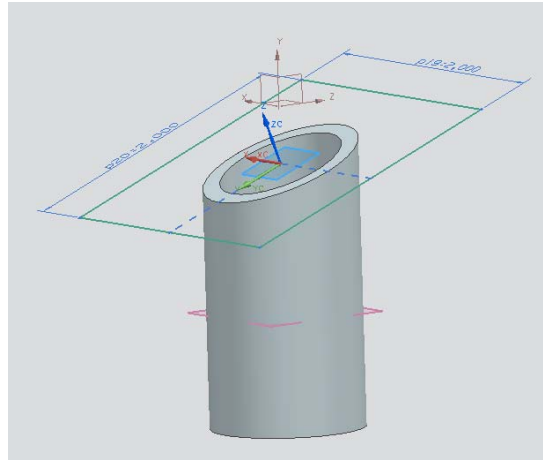


Figure 29b. Sketch of Plate on Angled Pipe.

Four .112-inch holes were then created using a subtraction extrusion. The holes will allow for the knee and shin to be bolted together by .112-inch diameter bolts and nuts. Figure 30b shows the model sketch of the holes on top of the plate.

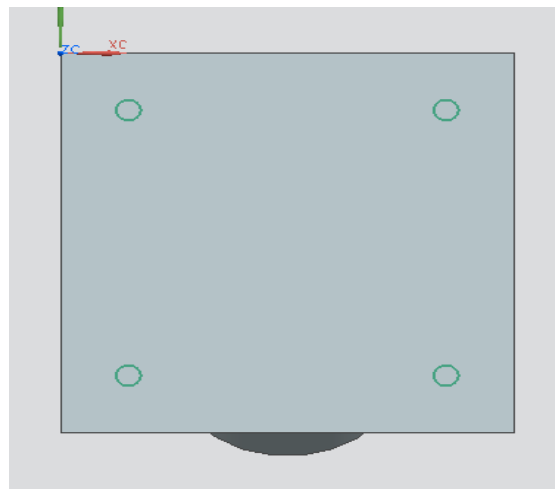


Figure 30b. Sketch of Holes.

The square edges were then rounded out using a .5-inch radius edge blend. The final model of the aluminum knee/shin interface part is shown in Figure 31b below.

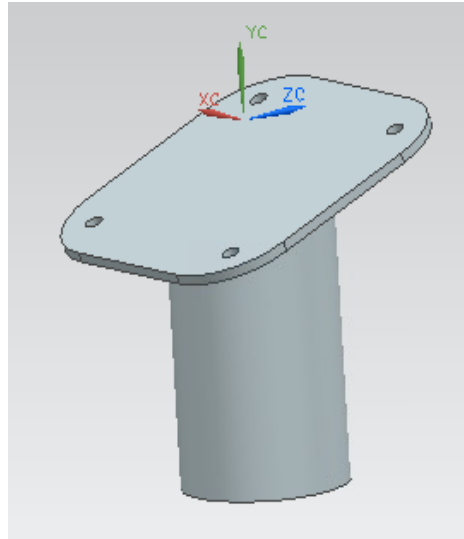


Figure 31b. Final Model of Knee/Shin Interface.

KNEE:

The knee part was created to interface between the user's knee and the shin assembly in the crutch. The user would place his or her leg in a bent orientation into the top of the knee part, and the knee part would be bolted to the shin assembly with four bolts. To begin the modeling process several different curves were created. Figure 32b shows the curves used for the process.

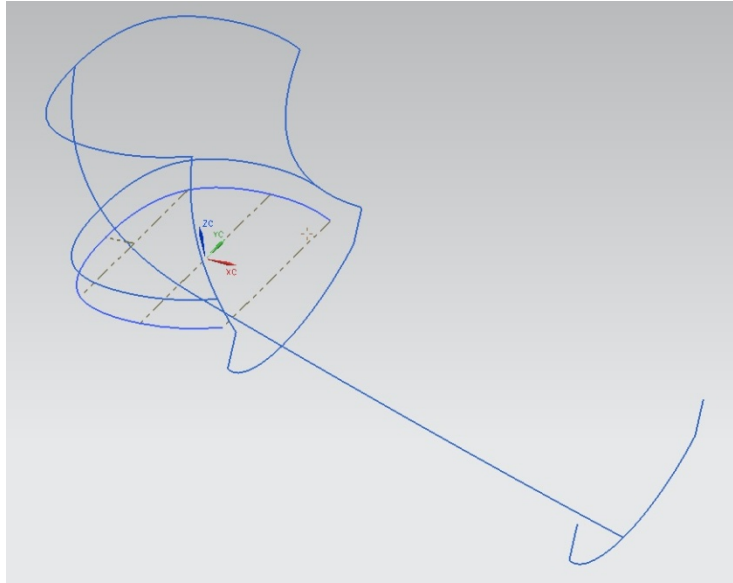


Figure 32b. Knee Curves

Two different profiles were created. The first profile was for the vertical section of the knee and the second profile was created for the lower half of the knee. Each profile was projected onto multiple planes to attain the proper spacing. A “backbone” curve was then created to go from the top profile of the vertical section to the bottom profile of the lower section. Two bounding curves were then created by connecting splines from the edge of the vertical profiles as well as the edge of the top profile of the lower section. Using the curves, surfaces were created. The first set of surfaces were created using the through curve mesh command. The backbone and bounding curves were used as the primary curves, and the profiles were used as the second curves. Figure 33b shows the surfaces created using this technique.

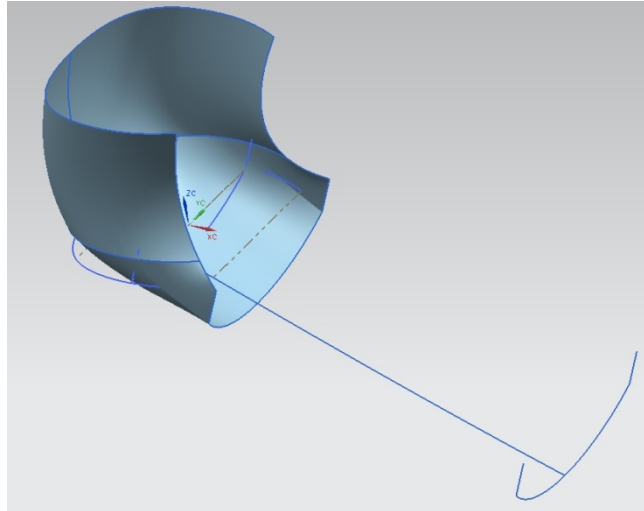


Figure 33b. Through Curve Mesh Surfaces

The next step of the modeling process was to create the lower half of the knee. To accomplish this, the through curve command was used to create a surface between the two lower section profiles. Figure 34b shows the resulting surface of this operation.

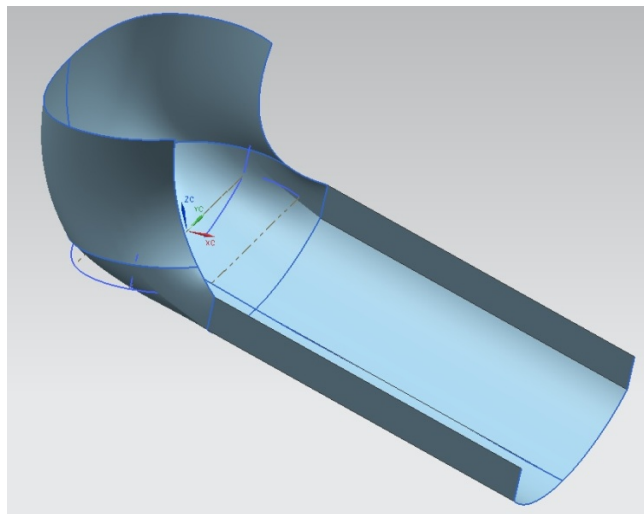


Figure 34b. Through Curve Surface

This sheet body was then transformed to a solid body using the thicken command. Once the solid body was created, the lower section was trimmed to the proper size by subtracting an extrusion.

The back edges of the vertical portion were trimmed using the same technique. Figure 35b shows the resulting solid.

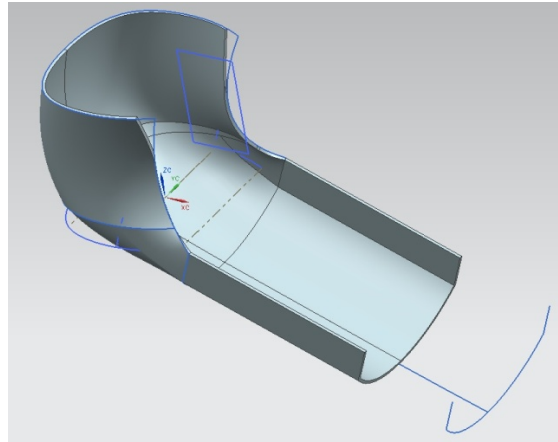


Figure 35b. Solid Body Trimmed

Once trimmed, the sharp corners were rounded using the edge blend command. Figure 36b. shows the rounded solid body.

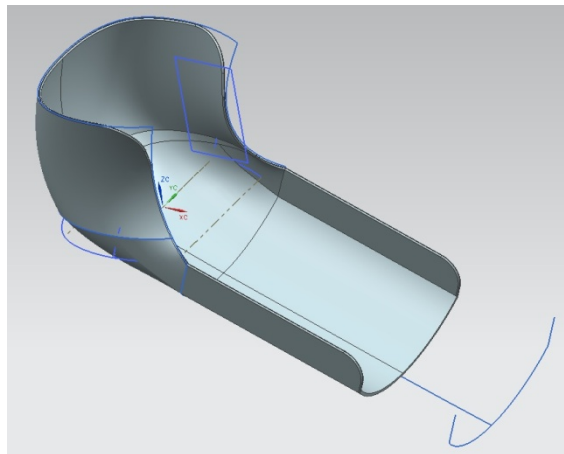


Figure 36b. Rounded Edges

The next step in the process was to create the flat surface for the knee shin interface part to bolt to. To create this feature, a square was extruded through the bottom of the knee. The trim body

command was used to delete the portion of the square extrusion that was extended into the interior of the knee part. Once trimmed, the unite feature was used to create one solid body from the two solids. Figure 37b shows the resulting model.

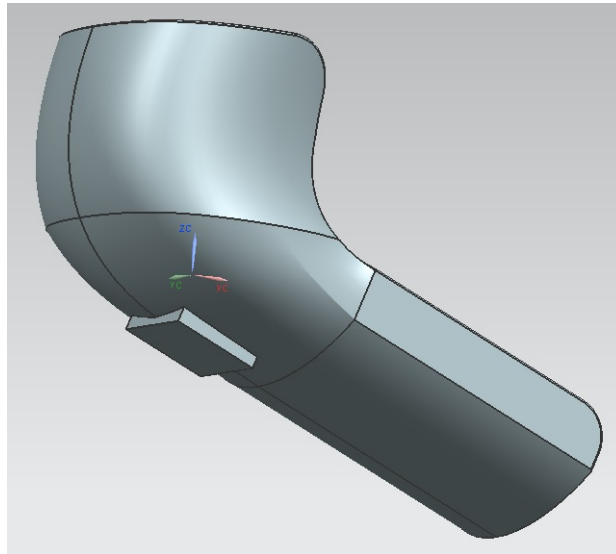


Figure 37b. Flat Extrusion

This extrusion was then blended into the bottom of the knee using the edge blend command. Once blended, the four bolt holes were extruded through the flat surface. Figure 38b shows the blended surface with the holes.

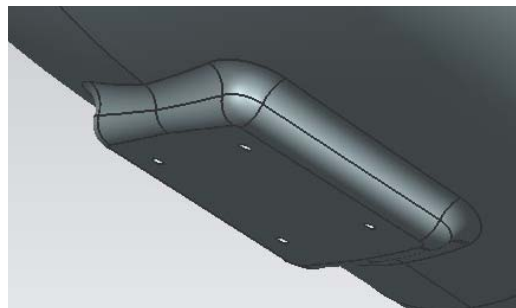


Figure 38b. Blended Flat with Holes

The final step in the process was to create the strap holes. An extrusion was used to create the two cutouts on one side of the knee. Once created, these features were mirrored across the center plane to create the cutouts on the opposite side. The edges of these cutouts were then rounded using the edge blend feature. Figure 39b shows the final model.

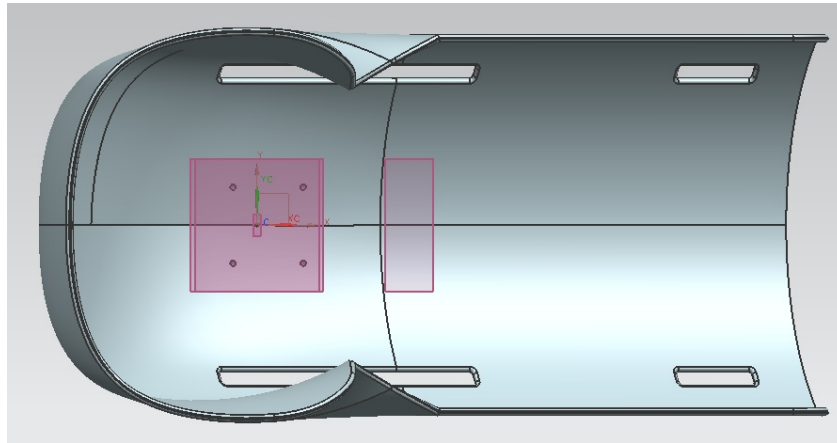


Figure 39b. Final Model with Straps

ANALYSIS:

PROBLEM 1: Bolt for Knee/Shin Connection (Stuart Boyer)

For the connection of the knee interface of the crutch and the shin interface of the crutch, four 4-40 .75 in. nuts and bolts will be used. These bolts must be able to sustain the shear forces produced at a 21° angle by a 300 lb. axial force. Internal forces were then to be calculated to see how much the bolt would displace under a worst case scenario of 300 lbs. Because there are four bolts of similar thickness and length, a FEA beam analysis was performed on only one of the bolts. The analysis of the one bolt could then be transferred to the three remaining bolts. The hand written beam analysis is shown below in Figure 1c. Figure 1c shows the bolt represented by the beam and then the calculated force of 26.88 lbs. represented by F. There is a distance of

1/8 in. of an inch between the bolt's top surface and point of force to represent the gap left by the material of the knee interface.

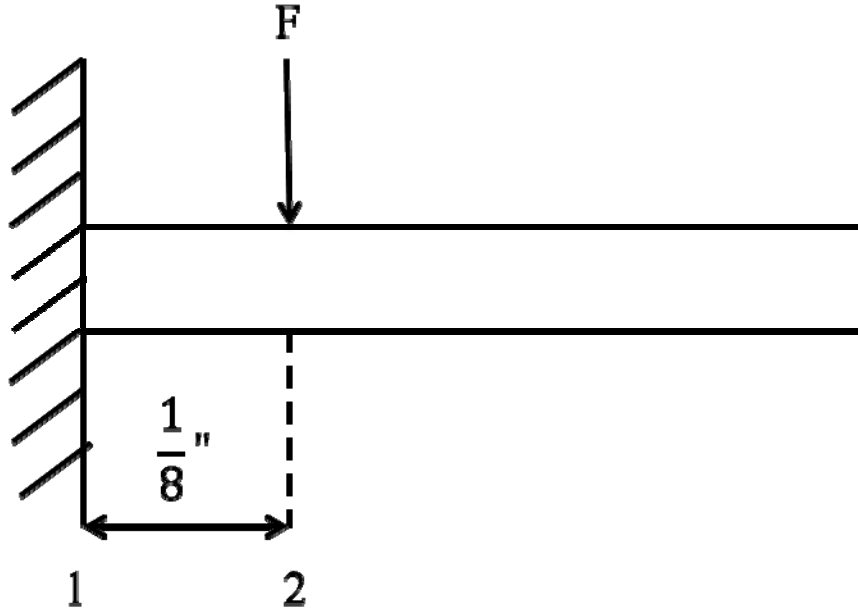


Figure 1c. Schematic of Bolt.

HAND CALCULATIONS:

The setup in Figure 1c shows that the bolt has a fixed end at node 1 and an external force at node 2. Eq.(1) is the beam element matrix setup to model the scenario shown in Figure 1c.

$$\begin{bmatrix} F_{1y} \\ m_1 \\ F_{2y} \\ m_2 \end{bmatrix} = \frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{bmatrix} d_{1y} \\ \phi_1 \\ d_{2y} \\ \phi_2 \end{bmatrix} \quad \text{Eq.(1)}$$

Boundary conditions were applied to the matrix in Figure 2c. Here the boundary conditions are that $m_2, F_{3y}, m_3, d_{1y}, \phi_1, d_{3y}, \phi_3$, were all equal to zero. Plugging in $L=1/8$ in., $E= 30 \times 10^6$ Mpsi,

and $I = \frac{\pi R^4}{4} = 1.961 \times 10^{-6} \text{ in}^4$ the four equations from Eq.(1) were solved and can be viewed in

Equation 2.

$$\begin{aligned} F_{1y} &= -12d_{2y} + 6L\phi_2 \\ m_1 &= -6Ld_{2y} + 2L^2\phi_2 \\ F_{2y} &= 12d_{2y} - 6L\phi_2 \\ 0 &= -6d_{2y} + 4L^2\phi_2 \end{aligned} \quad (\text{Eq. 2})$$

The system of equations was programmed into Matlab and the variables were solved for. The displacement and angle of the second node was calculated to be $d_{2y} = 7.4367 \times 10^{-5}$ and $\phi_2 = -0.0018$ radians.

FEA

The bolts were also analyzed using NX 7.5 NASTRAN FEA analysis. The bolt was given the material properties of steel and was constrained so that the bolt received a load of 26.88 lbs. perpendicular to the bolt, similar to the hand calculations as before. To constrain the bolt, it was first simplified to a simple cylinder and then the top of the bolt was held fixed. The bolt was then split into two bodies that were 1/8 in. away from each other. The 1/8 in. gap was set there to represent the material (knee interface) that was in between the top and bottom of the bolt. Next a force of 26.88 lbs. was applied to the contact area of the bolt on the upper 1/8 in. body. The mesh size was automatically picked by the program and results of the FEA analysis performed in NX 7.5 NASTRAN software are seen in Figure 3c.

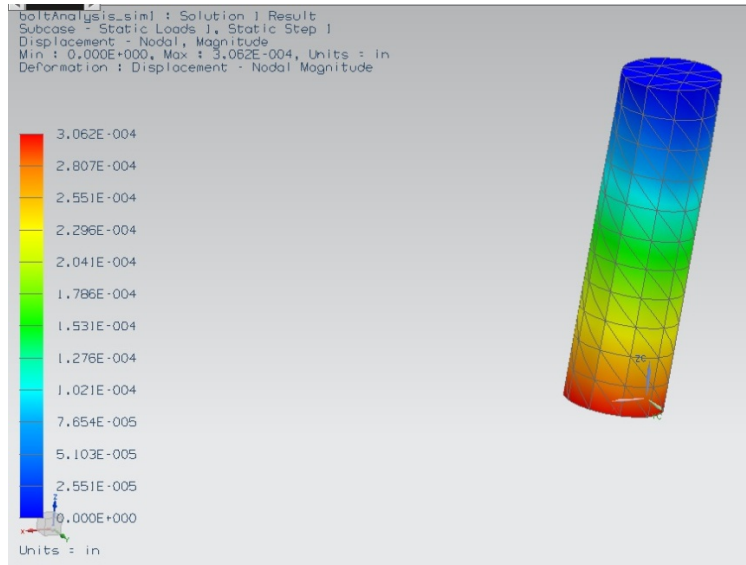


Figure 3c. NX NASTRAN View of Bolt Displacement.

The displacement of the bolt at a distance 1/8 in. from the top of the bolt calculated by NX 7.5 NASTRAN software was 7.654×10^{-5} inches whereas the hand calculation of the displacement was 7.4367×10^{-5} inches. These results agree within suitable reason.

PROBLEM 2: Adjustable Shin (Michael Notarnicola)

The design of our crutch requires that the user can range from heights of 5'2" to 6'2". This leads to many holes being placed radially around the pipe used for the bottom telescoping pipe. The telescoping pipes are held together with a locking pin that has a maximum shear of 2000 lbs. Since the pin's failure load is much higher than any load the crutch will experience the pipe is analyzed for failure. The pipe has an outer diameter of 1.05 in. and an inner diameter of 0.824 in. It is made of Al 6061, which has a Young's modulus of 10 Mpsi. The pipe is analyzed by fixing one end of the pipe and applying a load at the furthest pin hole of the pipe to simulate compression. The applied load was 450 lbs. or 1.5 times the maximum load that the crutch is weighted for.

HAND CALCULATIONS:

The finite element analysis was first performed by hand using the spring element method.

Figure 4c shows how the pipe was simplified and finite element method was applied to it.

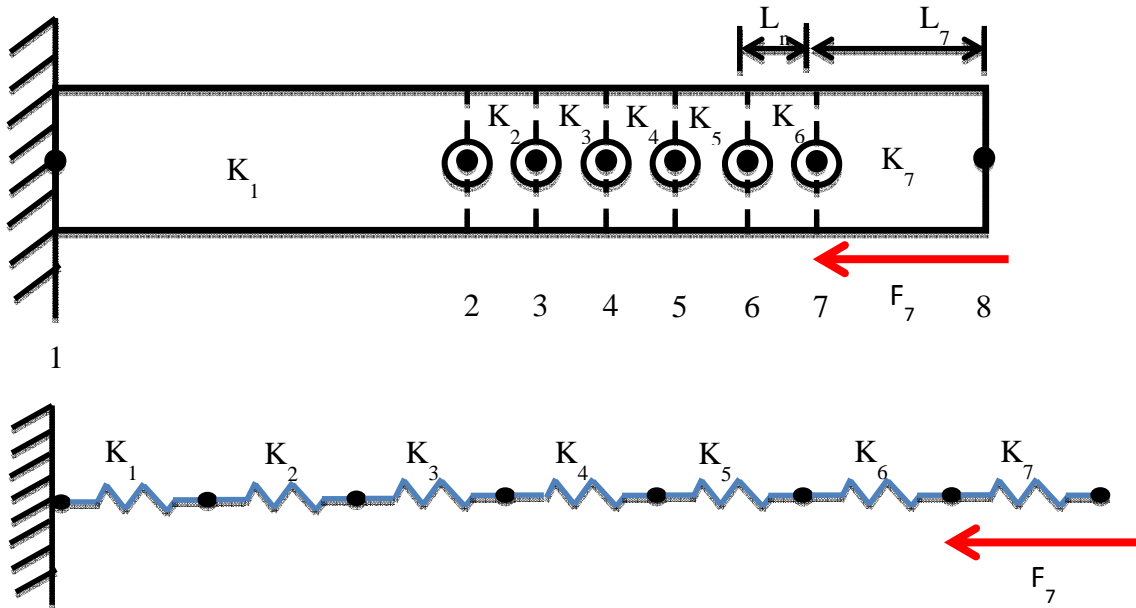


Figure 4c. Spring Element Theory of Adjustable Shin

Nodes 1 and 8 are the endpoints of the pipe, while nodes 2 through 7 are located at each pin hole.

The spring constants were calculated using Equation 3.

$$K = \frac{AE}{L} \quad (\text{Eq. 3})$$

In this equation A is the cross-sectional area of the pipe, E is the Young's modulus of the pipe material, and L is the length between the nodes. For K_1 and K_7 , the cross-sectional area was found by subtracting the outer diameter circle area from the inner. For K_2 through K_6 , the cross-sectional area was found the same as before, however an area of the thickness of the pipe by the

diameter of the pins holes was subtracted twice since these nodes cross-sections are located at the center of the pin holes. K_1 was found to be 550611 lbs./in. K_2 through K_6 were found to be 4333456 lbs./in. K_7 was found to be 1443590 lbs./in. Using these K values, Figure 5c shows the system in matrix form.

$$\begin{bmatrix} F_1 \\ F_2 \\ F_3 \\ F_4 \\ F_5 \\ F_6 \\ F_7 \\ F_8 \end{bmatrix} = \begin{bmatrix} k_1 & -k_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ -k_1 & k_1 + k_2 & -k_2 & 0 & 0 & 0 & 0 & 0 \\ 0 & -k_2 & k_2 + k_3 & -k_3 & 0 & 0 & 0 & 0 \\ 0 & 0 & -k_3 & k_3 + k_4 & -k_4 & 0 & 0 & 0 \\ 0 & 0 & 0 & -k_4 & k_4 + k_5 & -k_5 & 0 & 0 \\ 0 & 0 & 0 & 0 & k_5 & k_5 + k_6 & -k_6 & 0 \\ 0 & 0 & 0 & 0 & 0 & k_6 & k_6 + k_7 & -k_7 \\ 0 & 0 & 0 & 0 & 0 & 0 & -k_7 & k_7 \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \\ d_6 \\ d_7 \\ d_8 \end{bmatrix} \quad \text{Eq.(4)}$$

Node 7 has an external force of -450 lbs. applied to it leading to F_7 being equal to -450. Node 1 has a reaction force due to the external force leading to F_1 being non-zero. F_2 through F_6 and F_8 are all zero. d_1 is zero, while d_2 through d_8 are all non-zero. Solving this system lead to F_1 having a value of 450 lbs. The displacements were solved as follows: $d_2 = -8.17 \times 10^{-4}$ in. $d_3 = -9.21 \times 10^{-4}$ in. $d_4 = -1.025 \times 10^{-3}$ in. $d_5 = -1.129 \times 10^{-3}$ in. $d_6 = -1.233 \times 10^{-3}$ in. $d_7 = d_8 = -1.336 \times 10^{-3}$ in.

FEA

FEA was performed on the part file BottomOuter. The material and 3-D mesh were applied to the fem file. A fixed constraint was placed on the farther end of the pipe from the pin holes. A load of 225 lbs. was applied to each of the two in-line holes located the farthest away from the fixed end. Solving this in NX resulted in Figure 6c.

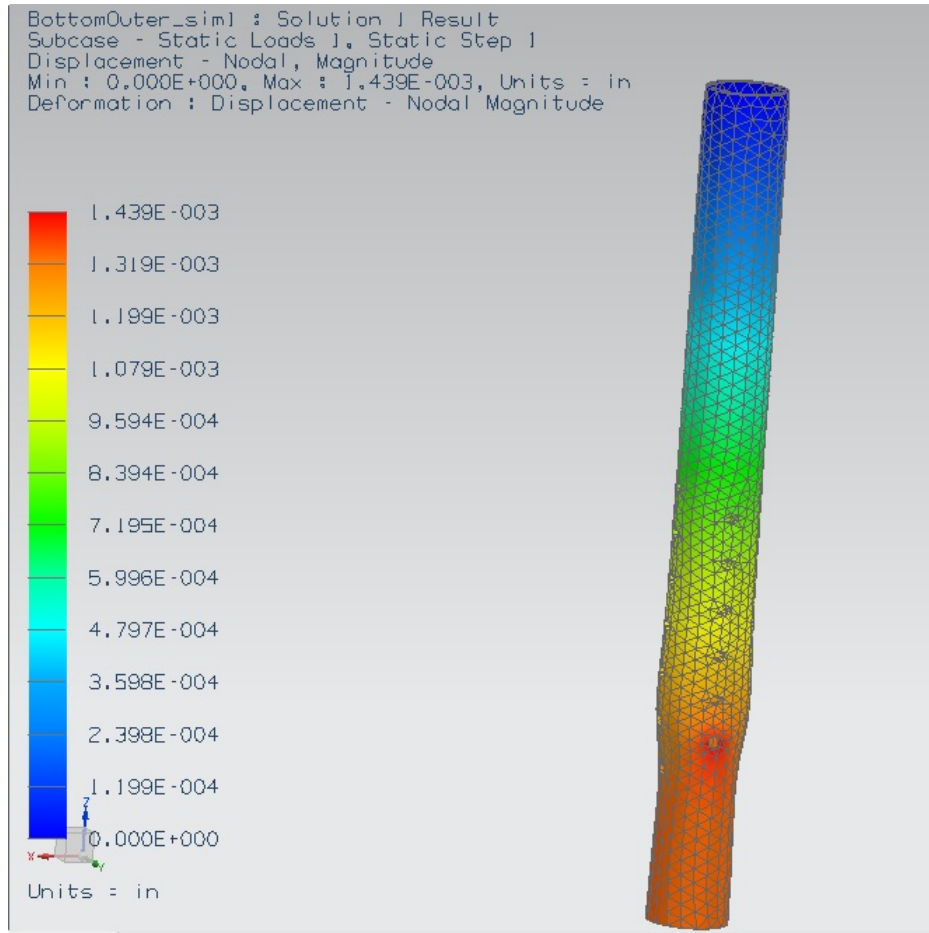


Figure 6c. FEA Results of Adjustable Shin Loading

The results of the FEA produced a maximum displacement of 1.439×10^{-3} in. at the farthest hole and a displacement of 8.394×10^{-4} in. at the closest hole. Comparing these results with the hand calculated results for d_8 and d_2 , respectively, shows that the analyses agree with one another.

PROBLEM 3: Spring Plate (Matt Karesh)

The spring plate is the interface between the bottom shin pipe and the spring in the heel. This plate allows for the force in the pipe from the user to be transferred to the spring. The spring plate also has an alignment tab to keep shin and knee assemblies in line with the foot and heel assemblies. This plate will see the full force from the user's weight and must be able to withstand

this force without failing. The plate was specified to be Al 6061 with $E = 10 \text{Mpsi}$ and a .125" thickness.

HAND CALCULATION:

Figure 7c shows how the spring, spring plate, and bottom skin pipe interface with each other.

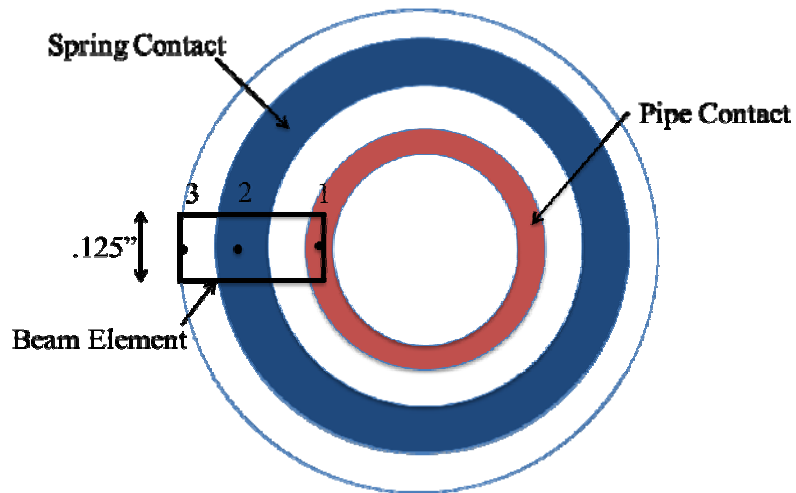


Figure 7c. Spring Plate Contact Areas

The pipe will contact the plate from above in the red highlighted area shown in the figure. The spring will interface the plate from below in the blue highlighted area. For simplicity, a section of the plate was analyzed as a beam element with a .125" width. The .125" width was chosen to match the .125" thickness of the plate and create a square element. The center of the pipe contact area was assumed to be fixed, and the force was applied to the center of the spring contact area. The node placements are shown in the figure as well. Figure 8c shows the simplified beam element.

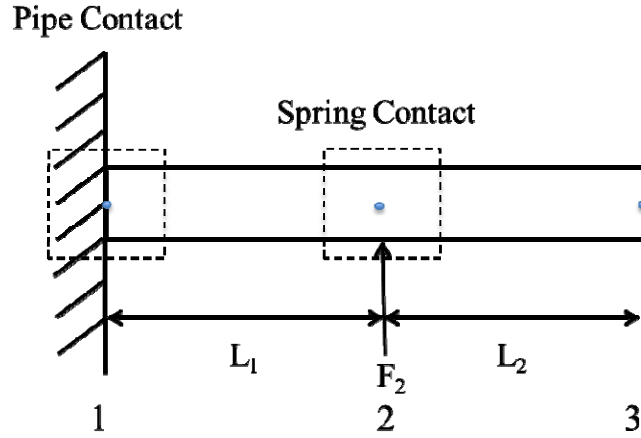


Figure 8c. Simplified Beam Element.

To calculate the force for the simplified element, the elemental spring contact area was divided by the total spring contact area to find the percent area being analyzed. The total force applied to the spring plate by the spring of 292.5 lbs was then multiplied by this percentage and applied to the element. This force was 6.9 lbs. Figure 9c shows the system of equations used to solve the beam element problem. This problem had two elements with different lengths. Therefore, the L_1 length was applied to all terms related to the first element and the L_2 length was applied to all terms related to the second element when the $\frac{EI}{L^3}$ term at the beginning of the matrix was multiplied through.

$$\begin{bmatrix} F_{1,y} \\ m_1 \\ F_{2,y} \\ m_2 \\ F_{3,y} \\ m_3 \end{bmatrix} = \frac{EI}{L_{(1/2)}^3} \begin{bmatrix} 12 & 6L_1 & -12 & 6L_1 & 0 & 0 \\ 6L_1 & 4L_1^2 & -6L_1 & 2L_1^2 & 0 & 0 \\ -12 & -6L_1 & 12+12 & -6L_1+6L_2 & -12 & 6L_2 \\ 6L_1 & 2L_1^2 & -6L_1+6L_2 & 4L_1^2+4L_2^2 & -6L_2 & 2L_2^2 \\ 0 & 0 & -12 & -6L_2 & 12 & -6L_2 \\ 0 & 0 & 6L_2 & 2L_2^2 & -6L_2 & 4L_2^2 \end{bmatrix} \begin{bmatrix} d_{1,y} \\ \phi_1 \\ d_{2,y} \\ \phi_2 \\ d_{3,y} \\ \phi_3 \end{bmatrix} \quad \text{Eq.(5)}$$

The moment of inertia was calculated using Equation 6

$$I = \frac{L^4}{12} = \frac{.125^4}{12} = 2.035 \times 10^{-5} \quad (\text{Eq. 6})$$

d_{1y} and ϕ_1 were set to 0 as boundary conditions, and the system was solved. This system yielded a d_{2y} of 4.8×10^{-4} in., ϕ_2 of 0.0096 rad., d_{3y} of 8.3×10^{-4} in., and a ϕ_3 of 0.0097 rad.

FEA:

This model of the spring plate was divided into multiple bodies that correspond to the divisions shown in Figure 10. The top face of the shin pipe contact area was fixed. A force of 292.5 lbs. was applied to the bottom face of the spring contact area in the upwards direction. All of the separate bodies were meshed using the auto size feature, and a glue coincident mesh mating condition was applied to the coincident faces of each of the bodies. Figure 10c shows the displacement results of the analysis.

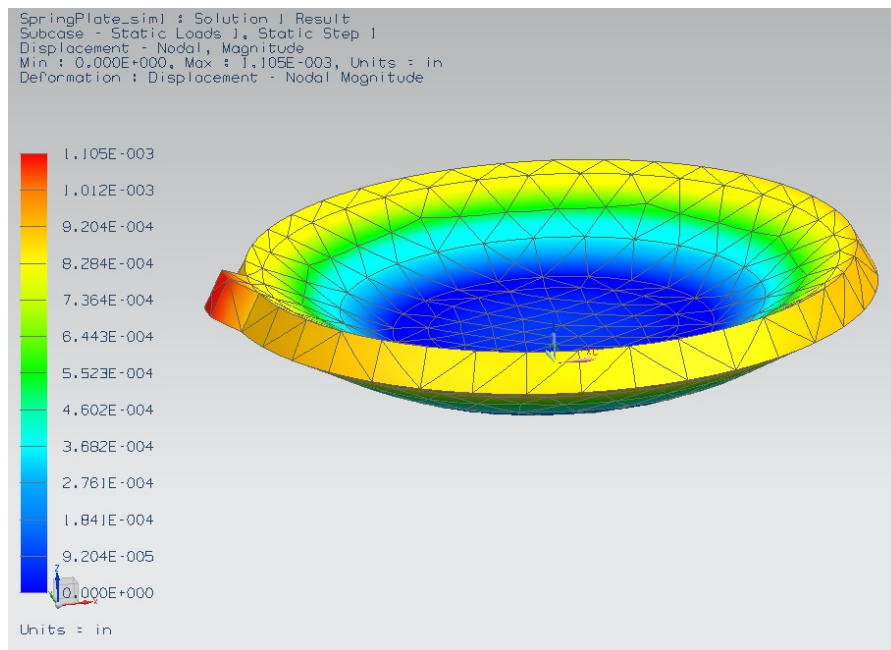


Figure 10c. Spring Plate FEA Displacement

The analysis yielded a displacement of about 8.284×10^{-4} at the edge of the plate. The maximum displacement of 1.105×10^{-4} was at the edge of the locator tab which was not included in the hand calculations for simplicity. The results of the two analyses agree and are acceptable for this design.

CONCLUSIONS AND FUTURE WORK:

The purpose of this project was to design a hands free replacement for standard crutches used by those with injuries at the foot or ankle. The crutch used a spring in the heel of it to dampen the ground reaction forces experienced in the crutch. Each part was designed using UGS NX CAD software. The splines used to create the complex parts were generated using points taken off a human foot. Once the parts were created they were assembled into the final product.

During the design process it was necessary to use FEA to design each part efficiently. Using safety factors on the loads applied to critical components the parts were tested for failure or overdesign. The FEA was done using hand calculations and then checked with computer simulations. For all of the design problems looked at, the hand calculations and computer simulations all agreed within sufficient reason with one another. The first problem looked at was the deformation of the bolts that hold the knee to the knee interface. The results determined the bolt size was appropriate for the designed load. The second problem looked at was the deformation in the shin due to buckling. The results determined that buckling would not be an issue with this design. The last problem determined whether the plate sitting on top of the spring would fail in the counter bore hole of the heel. The thickness of the spring plate resulted in little deformation under extreme loading. The FEA results provided reasonable belief that the design is sufficient to continue to the next phase of prototyping.

Further work to be done on this design includes checking for manufacturability of all the parts. The complex parts must be looked at in detail to ensure they can be created using modern manufacture processes. On top of this further testing will be done on the crutch considering it is a medical device and will require FDA approval to be released on the market. The design will also go through an industrial design phase to provide user aesthetics. The crutch will also be prototyped to look for failures and issues that cannot be seen on computer models. After several iterations of the described work the crutch is believed to open a new quality of life for those with foot and ankle injuries.