COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

DESIGN AND MANUFACTURE OF A FOOTBALL THROWER

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Director: Bruce Flachsbart

Madrid

Junio de 2019

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Fdo.: NAME Date: DD/MM/YYYY

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DESIGN AND MANUFACTURE OF A FOOTBALL THROWER

Autor: Inés Avello Solís

Director: Bruce Flachsbart

Madrid

Junio de 2019

DISEÑO Y FABRICACIÓN DE UN LANZADOR DE BALONES DE FÚTBOL AMERICANO

Autor. Avello Solís, Inés.

Director: Flachsbart, Bruce

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

RESUMEN DEL PROYECTO

Introducción

El proyecto consiste en el diseño y producción de un mecanismo que lleve a cabo el lanzamiento de una pelota de fútbol americano, siendo necesario que la pelota además de trasladarse gire alrededor de su propio eje. El sistema de lanzamiento por otros mecanismos existentes y dedicados a la esta misma tarea no podrá ser imitado ya que se requiere que el diseño sea innovador. La utilización de energía eléctrica asimismo está restringida.

Actualmente existen aparatos capaces de lanzar pelotas de fútbol americano a partir de energía eléctrica. Esta dependencia puede obstaculizar y aumenta el precio del conjunto. Como consecuencia, el desarrollo de un aparato mecánico no solo permitiría una producción más sostenible y mayor versatilidad, sino también un abaratamiento del precio total. Dichos objetivos interesan puesto que el público al que está dirigido este producto está definido.

El lanzador es un producto con un fin recreativo. Está dirigido a personas cuyo físico les impide participar en deportes, ya sea por su edad o por alguna discapacidad. Sin embargo, también está dirigido a niños y personas cuya coordinación imposibilita llevar a cabo esta actividad, ya que, aunque se trata de algo intuitivo, termina por ser una tarea difícil.

Metodología

Para la producción del lanzador se requirieron dos prototipos preliminares. El primer prototipo, aunque simple, permitió experimentar con la técnica con la que se conseguiría el spin de la pelota. Por consiguiente, el mecanismo de lanzamiento fue desarrollado en el segundo prototipo. Para el spin se utilizaron bisagras vivas producidas mediante impresión 3D. Gracias al

diseño de las bisagras flexibles, fue posible adquirir dos grados de libertad. Esto fue de gran utilidad porque permitieron una mayor libertad de movimiento para la pelota cuando era rozada por la bisagra viva. En la Figura 1 se pueden observar los grados de libertad de la bisagra viva y en la Figura 2 su disposición en el prototipo.

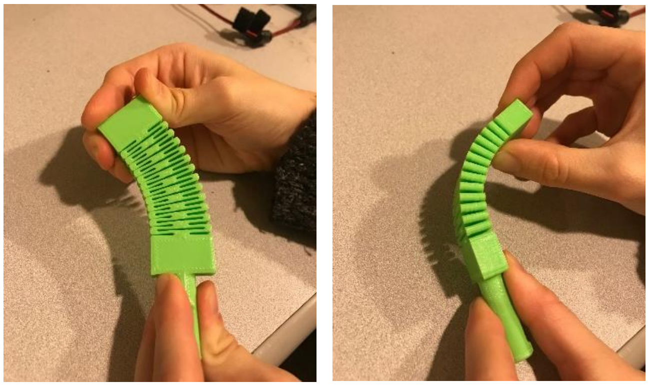

Figura 1. Bisagra viva flexionada

Figura 2. Primer prototipo

Puesto que este prototipo era incompatible con un sistema de lanzamiento tipo catapulta ya que se accionaba en horizontal y el balón no estaba sujeto durante la trayectoria, en el segundo prototipo se incluyó una base sobre la que se sostendría este sistema. A su vez, se hizo una funda en la que se incluyeron las bisagras vivas para una mayor sujeción de la pelota durante la trayectoria del lanzamiento. En la Figura 3 se observa el diseño en CAD del conjunto y otra más detallada de la funda.

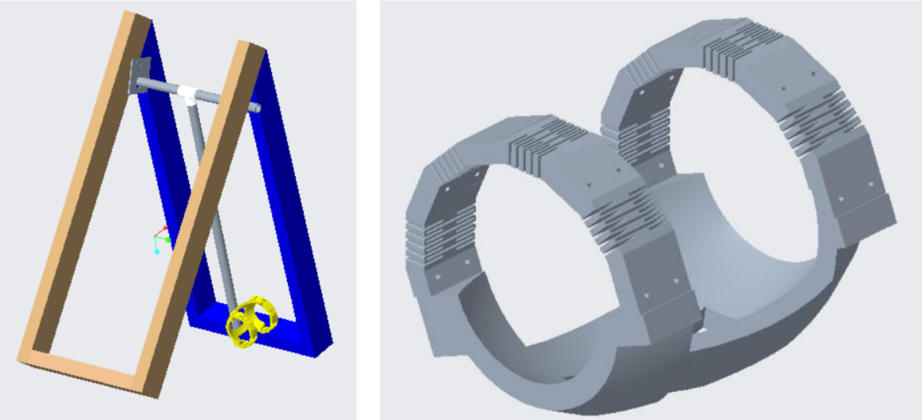

Figura 3. Diseño del segundo prototipo

Como se puede observar, la funda se diseñó en CAD de manera que se adaptase a la pelota de rugby. Puesto que uno de los objetivos era poder utilizar distintos tamaños de bolas, este diseño era útil gracias a la flexibilidad de las bisagras. Además, el hecho de estar fabricada mediante impresión 3D permitió pequeñas alteraciones de última hora.

Una vez se tuvo el conjunto, fue necesario incluir otro sistema para liberar la pelota en un determinado punto de la trayectoria. Después de investigar acerca de dichos sistemas se empleó un pasador atravesando dos solapas en la funda. De esta manera la funda se mantenía cerrada hasta que el hilo al que estaba conectado el pasador tiraba de él y permitía abrirla. Este sistema se consiguió por medio de una pajita, un cartón y alambre, como se puede ver en la Figura 4.

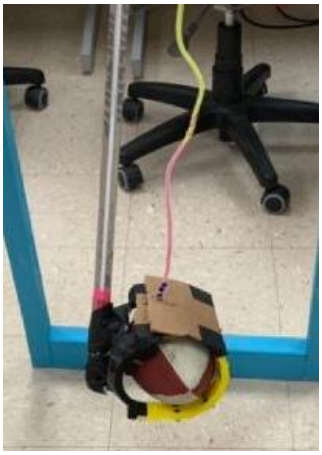

Figura 4. Sistema de liberación

Para la base se utilizó madera y tubos de PVC que conectaron la funda con la pelota al resto de la estructura. Se utilizó una lámina acrílica cortada por láser para las uniones entre los tubos con el marco. El resto de las uniones como la de la funda con el tubo vertical se realizaron con cinta americana. Como resultado el prototipo no era suficientemente estable y su vida útil era muy reducida. Mejorar estos aspectos fue la motivación principal del producto final.

Figura 5. Segundo prototipo

Para optimizar la durabilidad, estabilidad y aguante del prototipo era necesario mejorar las conexiones entre los elementos. Para ello fue necesario modificar el diseño de la funda que encerraba la pelota. Se añadió un extremo en el que poder insertar tornillos. Además, se modificó la forma de manera que admitiese mejor otros tamaños de pelotas.

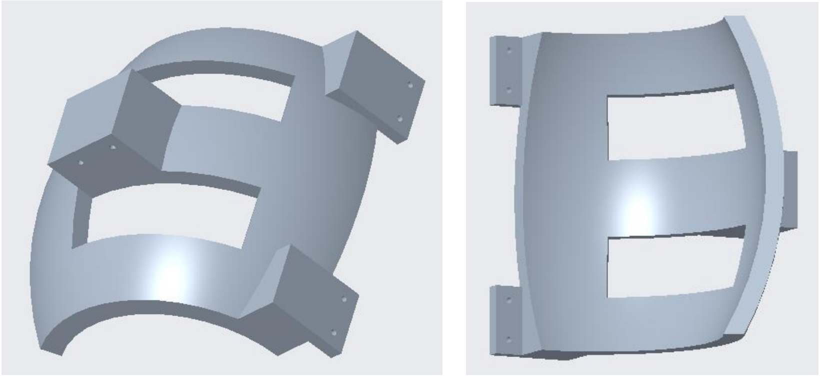

Figura 6. Diseño de la funda para prototipo final

De esta manera, la cinta americana entre la funda y el tubo vertical fueron sustituidos por otra unión. Dicha unión implicaba una mayor resistencia, pero también permitía variar el ángulo entre la funda y el tubo. Se empleó acrílico de nuevo, pero este material demostró no ser suficientemente resistente puesto que se rompió. En su lugar se empleó Delrin, ya que se trataba de un plástico más duro y se disponía de una placa con el doble de grosor que la del acrílico.

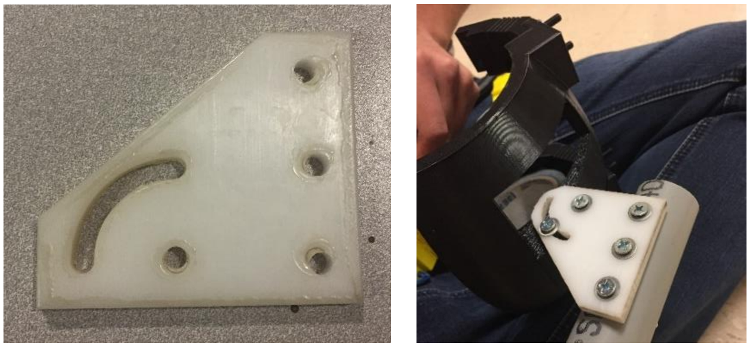

Figura 7. Elemento de unión entre funda y tubo vertical

A continuación, se mejoró el marco del que dependía la estabilidad de todo el prototipo. Una vez construida una base más rígida, se cambió la unión del tubo horizontal con el marco, de nuevo sustituyendo acrílico por Delrin.

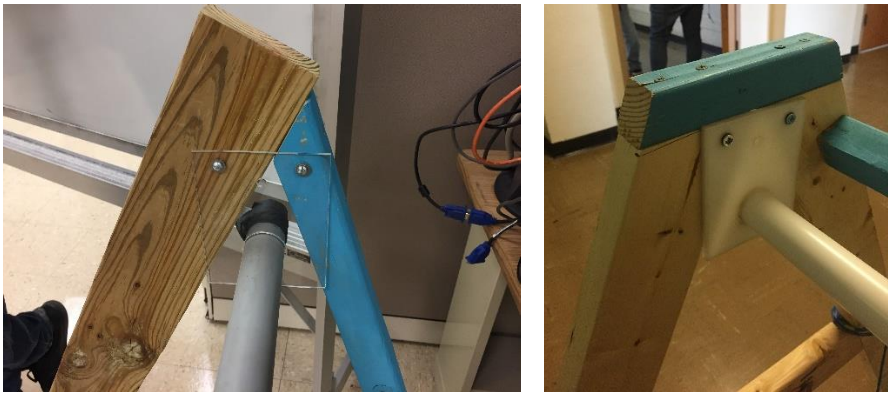

Figura 8. Comparación del marco en segundo prototipo y prototipo final

A pesar de que las bisagras vivas demostraron un buen funcionamiento, se diseñó otro modelo con mayor grosor para experimentar con distintas combinaciones de bisagras. El nuevo diseño se puede ver en la Figura 9.

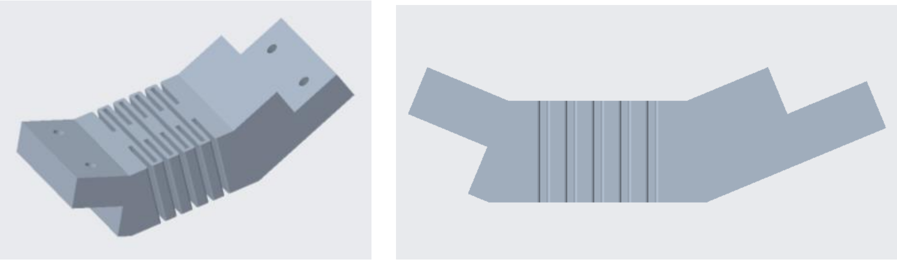

Figura 9. Diseño final bisagra viva

Por último, se mejoró el sistema de liberación al utilizar materiales más resistentes. En un principio se sustituyó el cartón por cadenas, pero esta opción resultaba demasiado pesada y entorpecía la salida de la pelota de su funda. Como consecuencia, emplear cuerda fue la mejor alternativa, ya que era ligera. Esta modificación también hizo posible el cambiar la posición del pasador a un lugar en el que era liberado con mayor facilidad. Esto se ilustra en la Figura 10.

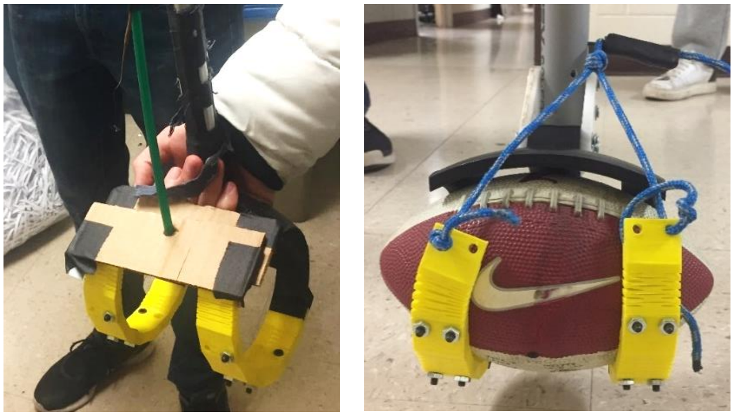

Figura 10. Comparación del sistema de liberación en segundo prototipo y prototipo final

Un objetivo del proyecto que no fue posible llevar a cabo fue la introducción de un muelle capaz de aportar la energía suficiente para el lanzamiento. Al experimentar con este elemento el spin del balón se veía perjudicado. El prototipo final, por tanto, se debía accionar a mano para producir un buen lanzamiento.

Resultados y conclusiones

El producto final fue el resultado de las mejoras realizadas en los prototipos. A pesar de que no se consiguió implementar el muelle, los restantes objetivos del proyecto fueron cumplidos. Se definieron variables que aún quedaban por determinar. Dichas variables eran: la combinación de distintos grosores de bisagras vivas y el ángulo de liberación del balón.

Se realizó un estudio para optimizar el producto, esto implicaba lograr el spin más estable. Tras la experimentación, se concluyó que, de las cuatro bisagras vivas disponibles en cada una de las tiras de la funda, la combinación de una bisagra gruesa con tres finas permitía un giro más estable. Por otro lado, se demostró que colocando la funda y el tubo con el ángulo mayor posible entre ellos era la mejor opción. Una vez definidas las variables el lanzador expulsaba la pelota con mayor facilidad. La calidad del lanzamiento también se vio mejorada notablemente. En la Figura 11 se puede observar el producto final.

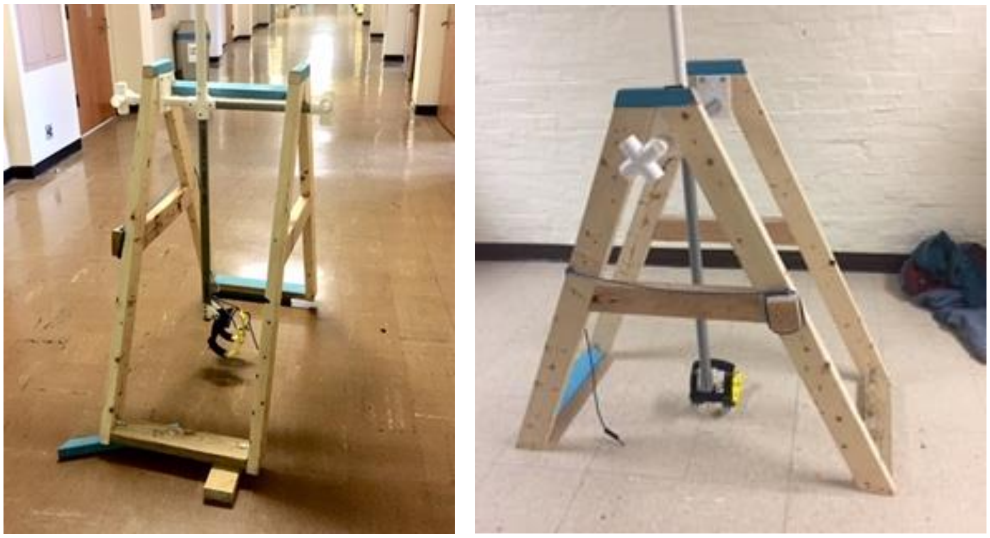

Figura 11. Producto final

DESIGN AND MANUFACTURE OF A FOOTBALL THROWER

Author. Avello Solís, Inés.

Director: Flachsbart, Bruce

Collaborating Entity: ICAI – Universidad Pontificia Comillas.

PROJECT SUMMARY

Introduction

The project consists in the design and manufacture of a mechanism capable of throwing a football, making it translate and spin on its axis. Other existing mechanisms dedicated to this task cannot be imitated, since it is required for the design to be a novelty. In addition, the use of electrical energy is not permitted.

At the time being, there are devices that can throw footballs with the help of electricity. This dependence can be inconvenient and rises the price of the whole set. Consequently, the development of a mechanical device would allow not only a sustainable production but also a decrease in the total price. These goals are of great interest since the public of this product is determined.

The football launcher is a recreational device. It is focused towards people whose physical situation avoids them from taking part in sports, due to their age or some kind of handicap. Nevertheless, it is also dedicated to children and people whose body coordination is an obstacle when trying to throw a football, since it is a difficult task even though it might seem intuitive.

Methodology

Two preliminary prototypes were required for the production of the launcher. The first prototype was simple but it allowed experimenting with the technique in which the spin of the ball would be achieved. For that reason, the throwing mechanism was developed in the second prototype. 3D printed living hinges were used to produce the spin of the football. Due to their design it was possible to have two degrees of freedom. This was very useful because the football

gained more freedom of movement when the living hinges rubbed it. In Figure 1, the two degrees of freedom can be seen, in Figure 2, their arrangement in the prototype.

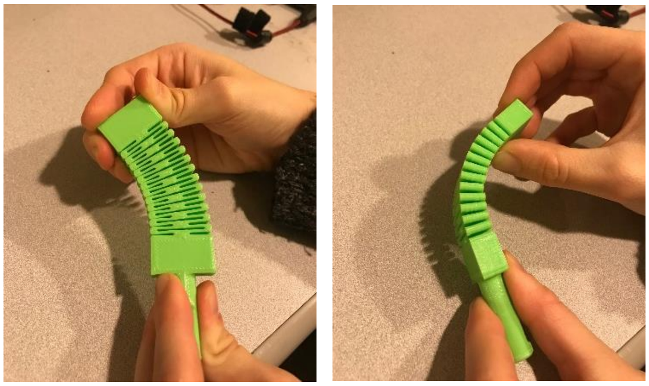

Figure 1. Bent living hinge

Figure 2. First prototype

Given that this prototype was incompatible with a catapult-like launch system since it was operated horizontally and the football was not held during its trajectory, the second prototype included a base for the launch system. At the same time, a case in which the living hinges were included was created to hold the ball during the throw. Figure 3 shows the Creo design of the set and a more detailed screenshot of the case.

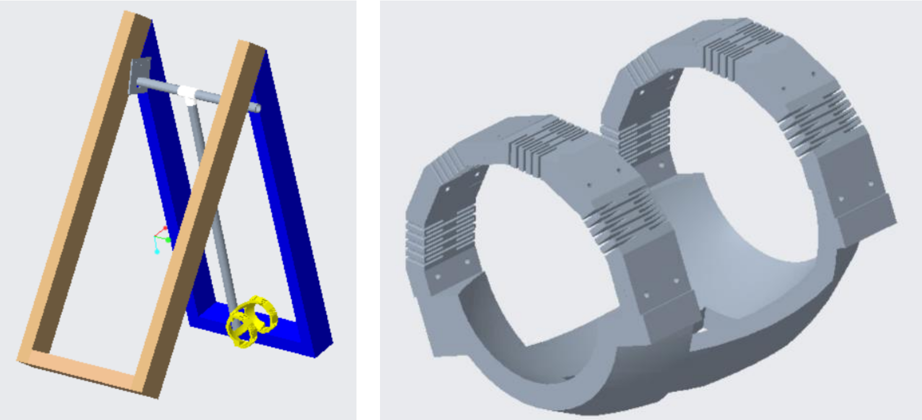

Figure 3. Second prototype Creo design

As the figure illustrates, the case was designed in Creo with a shape that could adapt to the football. The flexibility of the living hinges enabled the possibility of using different sized footballs, one of the objectives of the project. Additionally, the fact of manufacturing it with a 3D printer allowed last minute changes.

A release system was necessary in order to let the football free at a specific point of its trajectory. After doing some research on this, a pin release was used. The pin maintained the case closed until it was pulled back by a string, letting the case's straps open. This system was achieved using a straw, cardboard and a string as it can be seen in Figure 4.

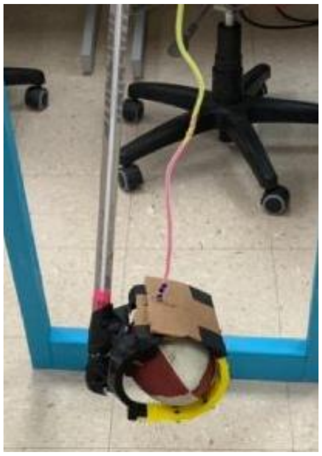

Figure 4. Release system

Wood and PVC tubes that connected the case to the rest of the structure were used. An acrylic sheet was laser cut to create the unions between the tubes and the frame. For the rest of the connections like the one between the case and the vertical tube, duct tape was used. As a result, the prototype was not stable enough and its useful life was short. Improving these aspects was the main motivation of the final product.

Figure 5. Second prototype

To optimize the durability, stability and resistance of the prototype it was necessary to improve the connections between the elements of the structure. For that reason, the case that held the football had to be modified. An extension was included in order to use screws. On top of that, its shape was also altered so that it could admit different kinds of footballs better.

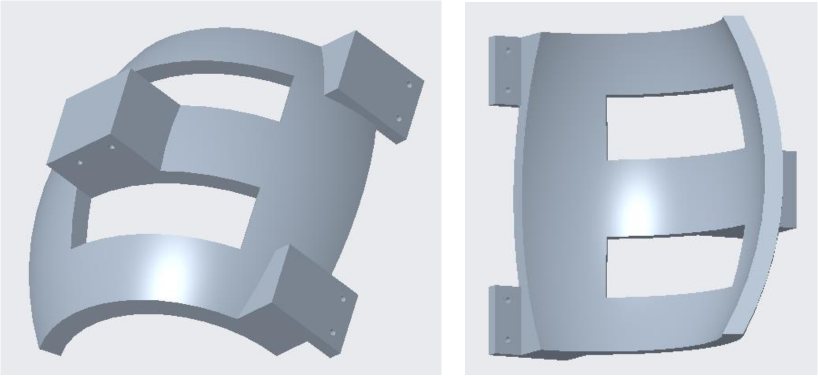

Figure 6. Case design for final prototype

The duct tape between the case and the vertical tube was substituted by another element. This element implied better resistance, but it also allowed varying the angle between the case and the tube. The sheet of acrylic was used again to manufacture it but this material proved to be insufficient when it broke. Delrin was used its place since it was a stronger plastic and the available sheets were double the thickness of the acrylic sheets.

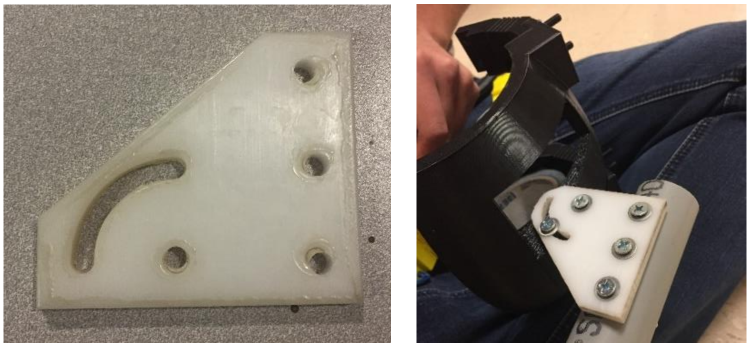

Figure 7. Connecting element between case and tube

The frame was also optimized since the stability of the whole product depended on it. Once it was built sturdier, the element connecting the horizontal tube with the frame was also changed for Delrin instead of acrylic.

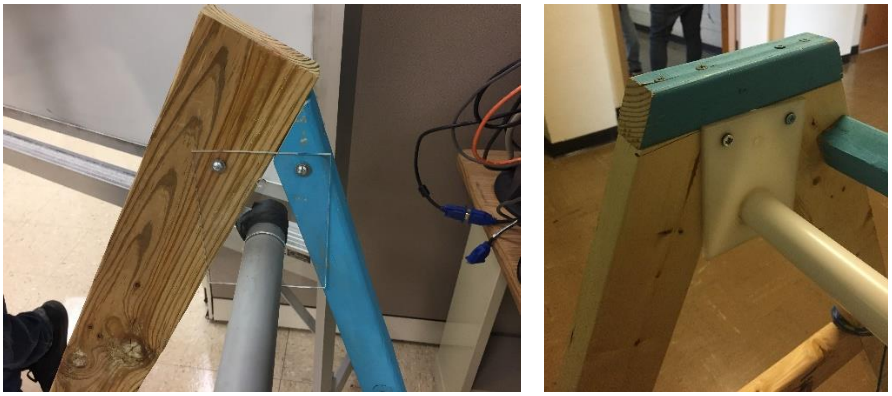

Figure 8. Comparison between second prototype and final product mount

Even though the living hinges proved to work well, a new design with more thickness was developed so that some experimentation with different combinations of hinges could be done. The resulting design can be seen in Figure 9.

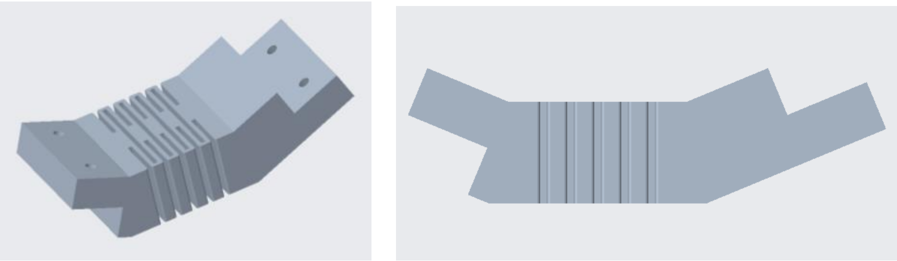

Figure 9. Final design of living hinge

Finally, the release system was also improved by using better materials. At first, the cardboard was changed for chains, however, this option was too heavy and hindered the exit of the ball from its case. As a result, rope was used in its place since it was lighter. This modification also made it possible to change the pin's position to one were it was freed easily. This is illustrated in Figure 10.

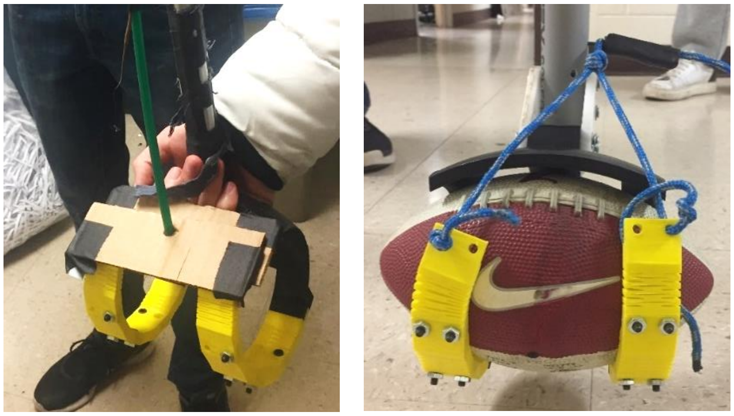

Figure 10. Comparison of release system in second and final prototype

A goal that could not be met during the project was the introduction of a spring that could give the energy necessary to power the launcher. While experimenting with this element the football's spin was worsened notably. The final prototype, as a result, had to be powered by hand in order to produce a good throw.

Results and conclusions

The final product was the result of improving the previous prototypes. Even though it was not possible to implement the spring, the other goals set for the project were achieved. Additionally, some of the variables left were defined. These variables were: the combination of living hinges with different thicknesses and the angle of release of the football.

A study was done to optimize the final product. By setting the aforementioned variables to its optimal arrangement, the spin could become more stable. After experimenting with them, it was concluded that, of the four hinges in each strap of the case, if one of the hinges was thick and the other three were thin the spin was affected positively. On the other hand, it was also proved that setting the case to its lowest position was the best option. Once this variables were defined the launcher threw the ball more easily. The quality of the throw experimented a significant betterment. The final product can be seen in Figure 11.

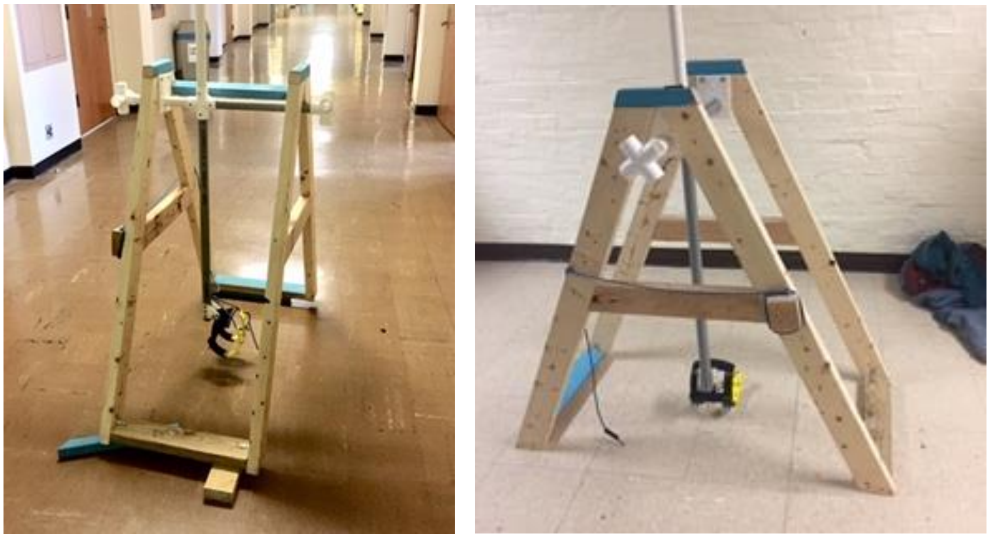

Figure 11. Final product

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1. Introduction

The purpose of this project is essentially oriented towards smoothing the small difficulties in life. It is clear that there are simple tasks such as playing sports that are sometimes taken for granted. The truth is, not everyone is capable of playing sports and as a result, they can not enjoy the benefits that they bring.

For this reason, this design will be focused in a popular sport that is known to be challenging, rugby. As a result, it is expected that the users of this machine will be able to catch and throw even if their physical situation complicates this task, enabling this activity to young and elderly people.

There are several intrinsic challenges to this project: to achieve a perfect spiral and to implement a simple mechanism that can be easily understood. Additionally, the current structure and system of electrical football launchers will not be imitated, this is a requirement for the design to be a novelty.

A study of numerous manufacturing techniques will be presented in an orderly fashion. These processes will be analysed to conclude whether they should be used in the manufacture of the final product. A durable but economic design is pursued since the product is advertised towards a wide range of people.

Finally, a sequence of prototypes will be shown with their advantages and disadvantages, hopefully arriving to an optimal deign where all the requirements are met.

2. Background Research

2.1 Current football throwers

Existing football throwers are very expensive, they cost $2000 (1778€) at least. Two spinning wheels replicate the spin a person gives the ball when throwing it. They either use a battery or are land powered.

Figure 1. Current football throwers [Source: Football Passing Machine™ - Jugs Sports]

They typically have an adjustable angle from 30º to 60º. Depending on the design they appear to be more or less portable. As mentioned before, this method to throw footballs is conventional and, therefore, it will not be used as inspiration fo the launch system.

All the devices researched had a dependency on electricity. For that reason, a mechanically powered football launcher could be a appreciated since it allows playing on any kind of site and it is eco-friendly.

2.3 Launch systems

- Trebuchet: A trebuchet works by using the energy of a falling counterweight to launch a projectile, using mechanical advantage to achieve a high launch speed.

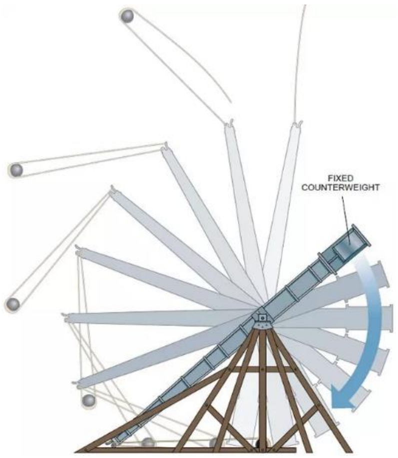


Figure 2. Trebuchet [Source: https://images.app.goo.gl/ysmGJbpmoJdvTgw56]

- Compound bow: All bows use the mechanical advantage of leverage to store energy in flexed limbs as you draw them. This is how they shoot an arrow faster than you could throw one. The compound bow puts greater energy behind the arrow, so it flies faster and straighter.

Figure 3. Compound bow [https://binged.it/2xn7btq]

3. Manufacturing Techniques

3.1 3D Printing

There are several 3D printing techniques that could be used. A research on the advantages and disadvantages of four of them will be done in order to choose which of them could be potentially used. It will also be decided if it will be implemented on the prototype or the final product depending on its characteristics.

3.1.1 SLA

SLA, in general, uses less support material when compared to other methods. It can also achieve the highest resolution and smoothest top surface compared to other RP methods. SLA can make clear rigid polymers, which is an advantage in terms of aesthetics. Unfortunately, there is no easy way to remove support scaffolding when using this method. Additionally, since the material is brittle, the part could crack easily while a thin part could warp.

3.1.2 SLS

SLS utilizes a stronger material that can be later machined. This method does not require support structures, unlike other printers. However, the two main drawbacks of SLS are that only one colour can be used and the surfaces are rough and porous.

3.1.3 FDM

The main advantages of FDM are that it supports the largest volumes and provides the fastest fabrication. The downside to this is that thin features tend to warp and overhanging structures require large amounts of support material. FDM is also the least precise of all the 3D printing methods.

3.1.4 MJP

MJP has the ability to print in a wide array of colours and has the rare trait of being able to produce flexible elastomers. MJP also has the unique advantage of being able to print extremely thin parts, where the other 3 printing methods struggle with warping. The drawback is that these elastomers rip easily and the support material requires 100% volume which could make printing very costly.

To conclude, the FDM technique will be chosen due to its capability of producing large volumes but above all, because of the fast fabrication it offers. This characteristic is deeply appreciated when it comes to the prototype since it allows small changes.

3.1.6 Results and discussion

Since this method is going to be used throughout the whole project, a deeper experimentation with printing is done. To truly understand this method's limitations, a support brace with holes was designed in Creo and printed using FDM.

Figure 4. Support brace

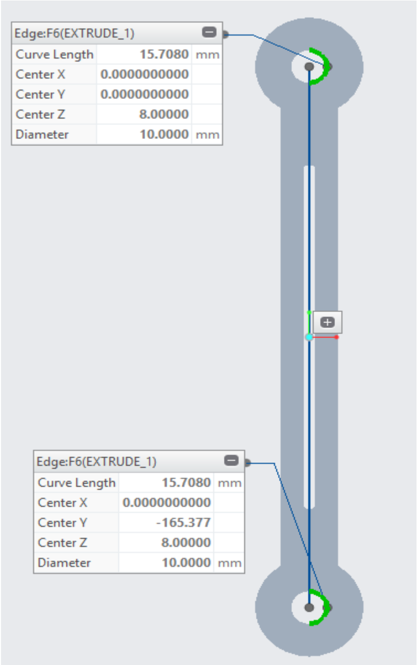
Due to the part being slightly larger than intended, the model was scaled down by 80% before printing.

Table 1: Comparison of measurements between Creo and 3D printed support brace

Measurement/Parameter	**Creo**	**Print**
Hole Diameter	10.000 mm (for both)	9.80 mm and 9.78 mm
Shaft Inner Width	3.000 mm	3.06 mm
Shaft Outer Width	16.000 mm	16.13 mm

From this table we can conclude useful information for the project's prototype. The printed part differs from the Creo model in different ways. Most importantly, the final part was slightly larger in each major dimension.

For instance, the printed part has slightly smaller inner hole diameter measurements. Initially, the part was designed to have two 10.000 mm holes; however, the dimensions ended up being 9.80 mm and 9.78 mm.



Edge:F6(EXTRUDE_1)

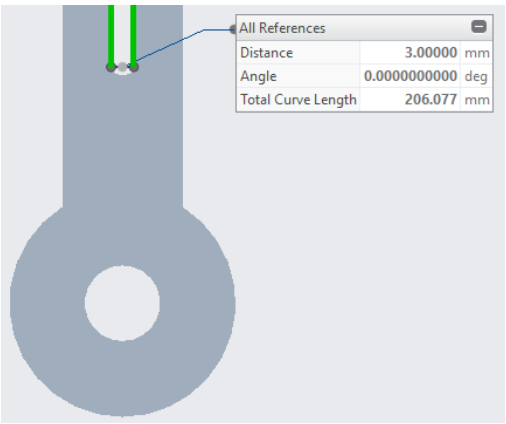
Curve Length	15.7080	mm
Center X	0.0000000000	
Center Y	0.0000000000	
Center Z	8.00000	
Diameter	10.0000	mm

Edge:F6(EXTRUDE_1)

Curve Length	15.7080	mm
Center X	0.0000000000	
Center Y	-165.377	
Center Z	8.00000	
Diameter	10.0000	mm

Figure 5. Inner hole diameter measurements

The inner dimensions of the shaft were also altered in the 3D printing process. The inner width of the shaft was meant to be 3.000 mm but ended up being 3.06 mm.

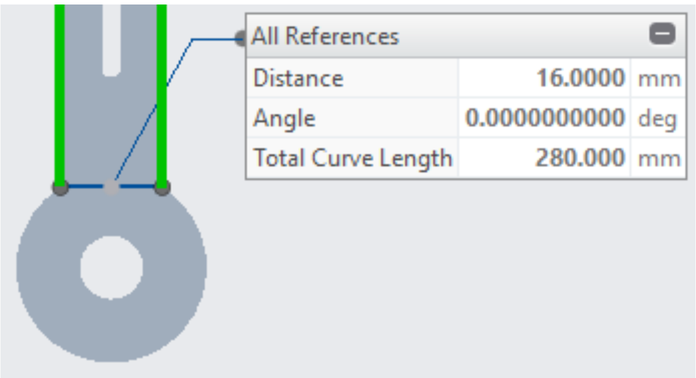


All References

Distance	3.00000	mm
Angle	0.0000000000	deg
Total Curve Length	206.077	mm

Figure 6. Shaft inner width measurement

Additionally, the outer width measurement of the shaft was also enlarged from 16.000 mm to 16.13 mm.



All References

Distance	16.0000	mm
Angle	0.0000000000	deg
Total Curve Length	280.000	mm

Figure 7. Shaft outer width measurement

The part was oriented such that the holes faced the ground. This orientation was chosen to reduce the print material needed in support structures by reducing the number of overhanging structures. Additionally, this orientation provided the smoothest finish for the two holes as there would be no support structure to tear off that may create imperfections. The only other optimal orientation would be to flip the part 180 degrees such that the top face is now on the bottom. This would produce the same quality as the other orientation since the part is symmetrical on both sides. A poor orientation would be to place the part on its side such that the holes are perpendicular to the ground. This would cause support structures to be needed for each hole and the entire shaft as these would be overhanging structures. By having support structures in the holes, tearing them off afterwards would create rough bumps.

The type of 3D printing used for the part also should change how the part is designed and what to expect from tolerancing and support structure. If this part was printed using SLS, surprisingly there would only be a few minor differences. Some of the major differences in SLS and FDM is that SLS doesn’t require any support material, has a better resolution, and uses different materials. Since this design doesn’t use any support material in FDM, the support structure makes no difference in SLS. Another difference that wouldn’t have a large effect on the final part for this design is the resolution. Luckily this poor resolution in FDM doesn’t make a significant difference in the final print’s uses.

3.2 Machining

Machining is a process where a raw material is turned into something else of a desired final shape and size. This may be done through material-removal like cutting, drilling or boring or through material addition. Machining is most commonly used with metal products but can also be done with other materials like wood, ceramic, plastic and composite materials.

Figure 8. Drilling [https://binged.it/2xlYmzI]

This process could be useful for the project in hand, not only for the prototype but for the final product. Additionally, it can be applied as a previous step to injection molding, another process interesting for this project. Knowing this, the research done on machining was directed towards the research on injection molding. A metal block was machined so that it could later be used as a mold.

3.2.1 Results and discussion

The design for the mould was inspired by the Illini Solar Car's logo and consisted of two overlapping hoops. Since we needed different levels to test the method's accuracy, one of the hoops was designed deeper than the other. Consequently, this constraint made rounding the sides harder.

Additionally, to make the circles appear as hoops, the inside edges had to be significantly rounded. Another constraint was that all the sides had to be tapered to create a draft angle so that the injection molded part would come out easily. For this reason, a two degree draft angle was added to all of the inside edges.

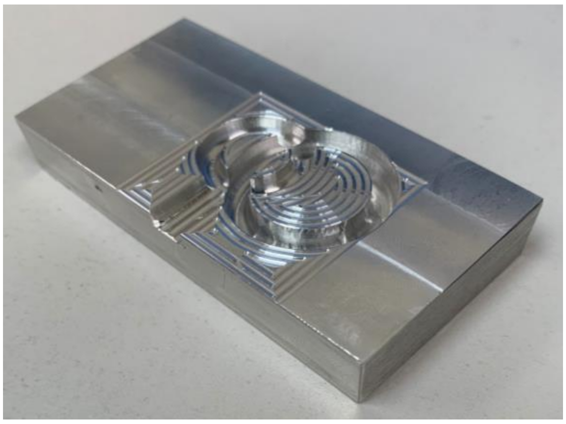


Figure 9. Machined mold

There were a few differences between the machined part and the Creo model. The most obvious was that the finished part had a patterned surface finish. The Creo model was designed to have a smooth surface, but the machining process resulted in a part with a rougher surface.

There were also some defects on the machined part. This is a clear example of how machining is not perfectly accurate, which is something to keep in mind if this process is used for the project.

In order to eliminate the differences mentioned above. An option is reducing the step over to improve the surface finish. Using an end mill instead of a ball mill would also improve the surface finish. Additionally, using tools with a smaller diameter might eliminate some small defects noticed in the final part.

3.2.2 Machining time optimization

Reducing machining time is an important task to lighten the manufacturing process. For that reason, a list of factors that can achieve this will be presented.

In order to reduce machining time, we can increase the step over in the finishing sequence. The step over is how far from the previous cut the next cut occurs, so if the step over is increased, the machining time can be reduced. However, this action would lead to a worse surface finish.

We can also increase the cutting speed to reduce machining time. This also comes with a drawback, increasing the cutting speed will decrease the tool life. For a single part, the decrease in tool life will not be noticeable, but over the lifetime of the machine, having lower tool lifes can be expensive, time consuming, and dangerous.

3.3 Injection molding

Injection molding is a process where plastic is shaped by melting it and injecting it into a predesigned mold. The mold is clamped under pressure to ensure a successful injection and cooling process. The resins fed into the machine fall into the injection barrel where they are heated to a melting point. The melted resins are then injected into the mold through a screw or a ramming device. The plastic cools to its final shape inside the mold.

This manufacturing process is typically used in mass-production since it has low scrap rates and once the initial costs have been paid, the price per unit is extremely low. Therefore, it could be useful for the production of the final design but not for the prototypes if you do not have a machine to your disposal.

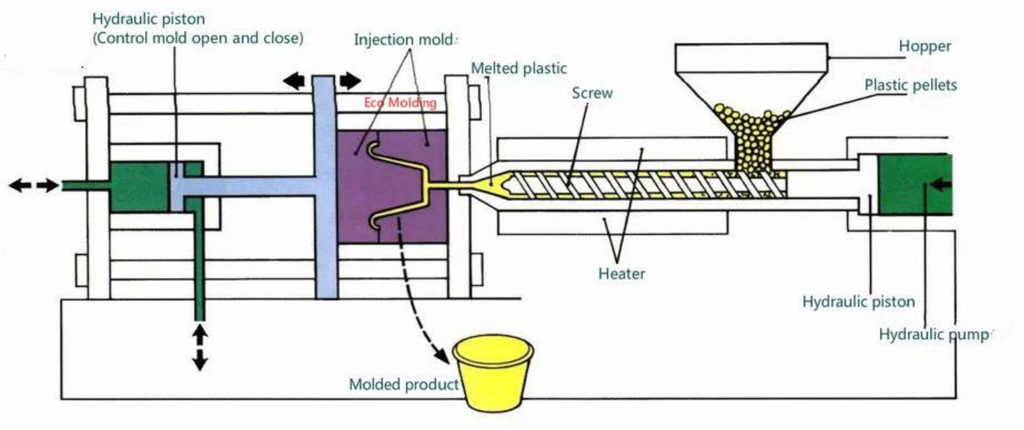


Figure 10. Injection molding diagram [Source: http://www.ecomolding.com/plastic-injection-molding/]

The software Moldflow was used before carrying out the process. Moldflow is a plastic injection and compression simulation used by engineers and analysts to improve plastic part designs, injection mold designs and manufacturing processes. In this case, it allowed a prediction of the resin-filling pattern to identify areas the resin can not impregnate. This software is incredibly useful to evaluate previously whether the part you are interested in creating can be done through injection molding or if it may be too complex for this process. As a result, it can save a lot of money on useless investments.

3.3.1 Results and discussion

As mentioned earlier, the part used for the experiment consisted of two overlapping circles placed at different depths. As shown in the image below, the two circles differ in diameter with the larger circle overlapping the smaller one at the top and bottom (assuming the gate is the bottom).

Figure 11. Injection molded trials

One problem predicted by the Moldflow software was that the outer edge of one of the rings would have inadequate fill quality. This caused the ring in the actual part to have a missing section corresponding to that area. The software also predicted that the bottom right corner would be filled last, creating an uneven fill quality across the part. Both of these issues can be solved by fixing the gate location to a more central area of the part so that the part fill is more symmetric.

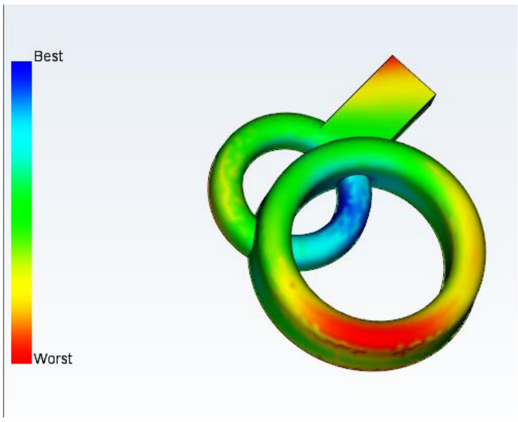


Figure 12. Moldflow part simulation

Figure 13. Created part

A recurring defect was the collection of excess material surrounding our part. The injected material leaked from the mold and appeared to enter a gap between the machined part and the holding block. This defect most likely occurred because the machined part was slightly smaller than the gap in the holding block. Increasing the size of the machined part or decreasing the size of the gap in the holding block would solve this issue.

Once our designed mold had been tested, it was decided to use a mold of a spiral instead. Since there were other groups that were also experimenting with injection molding, this let us compare measurements with each other, gaining a more precise knowledge of the process.

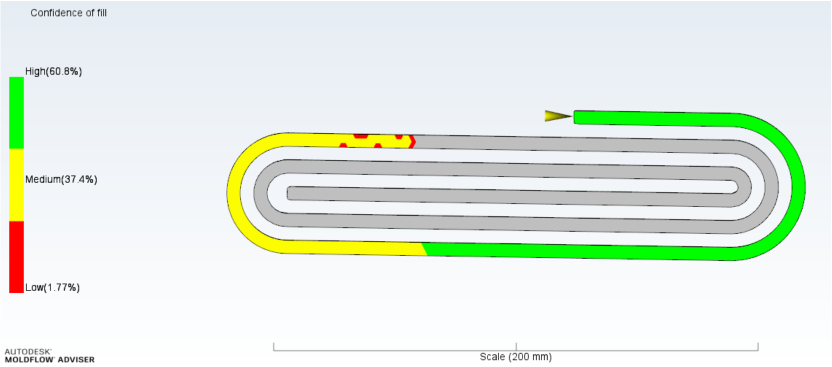


Figure 14. Capture of Moldflow prediction for spiral mold

Using the spiral mold, the software was used to predict the confidence of fill at three different temperatures (325 F, 350 F and 375 F) and three different pressures (40 psi, 50 psi and 60 psi).

Table 2: Conversion of temperature and pressure

Process	**Temperature**			**Pressure**		
MoldFlow Simulation	163°C	177°C	190°C	31 MPa	39 MPa	47 MPa
Mini-Jector Molding	325 °F	350 °F	375 °F	40 psi	50 psi	60 psi

Using the percentages of high, medium and low confidence of fill given by MoldFlow and some other parameters of the machine and resin used, a predicted length was calculated. This prediction was the length of the spiral that the machine was supposed to fill experimentally. The same measurements were registered later in the laboratory so that predicted and experimental lengths could be compared to evaluate the quality of the simulation.

Table 3. Comparison between predicted length and experimental length

Temperature (°C)	**Pressure (MPa)**	**Predicted total length (cm)**	**Experimental length (cm)**	**Percent difference (%)**
163	31	31.75	30.48	4.0
163	39	39.37	35.56	10.8
163	47	43.18	40.64	6.1
177	31	36.07	31.75	13.2
177	39	42.42	41.91	1.3
177	47	47.75	44.45	7.7
190	31	40.13	39.56	12.5
190	39	47.24	44.45	6.3
190	47	54.36	45.72	18.7

From the previous table it is visible that the predictions for the total length in MoldFlow were accurate since they were very similar to the experimental results. The biggest difference takes place for the temperature of 375 F and the pressure of 60 psi. There would not be such a big difference if the material had not been discontinued along the mold, leaving a few inches unaccounted for.

Comparing the values from the table we can also see that the percentages obtained are all positive. The reason for this is that the total length predicted by MoldFlow is greater than the experimental one. This should not be a surprise since the predicted length takes into account the low confidence of fill length as well.

The same table was done but this time to compare the high confidence of fill given by MoldFlow and the experimental measurements.

Table 4. Comparison between high confidence fill length and experimental length

Temperature (ºC)	**Pressure (MPa)**	**High confidence of fill lengths (cm)**	**Experimental length (cm)**	**Percent difference (%)**
163	31	19.81	30.48	-35.2
163	39	24.89	35.56	-29.8
163	47	27.94	40.64	-31.5
177	31	21.84	31.75	-31.1
177	39	26.42	41.91	-36.9
177	47	24.13	44.45	-45.6
190	31	23.88	35.56	-32.6
190	39	24.13	44.45	-45.6
190	47	34.04	45.72	-25.6

The percent difference between the high confidence of fill length and the experimental length is always negative. Similarly to the previous case, this can be explained from the fact that the high confidence of fill length does not account for those parts of the mold that could possibly be filled with lower confidence.

Obtaining negative values also implies that the length of the mold that was highly predicted to fill did actually get filled. As a result, MoldFlow's high confidence predictions are reliable. Based on the tables with percent difference, neither pressure nor temperature is more accurate at predicting the flow lengths.

Another interesting observation that could be done using the experimental values is which parameter, whether the temperature or the pressure, has a bigger influence on the rate of fill of the mold. The following graphs can illustrate this.

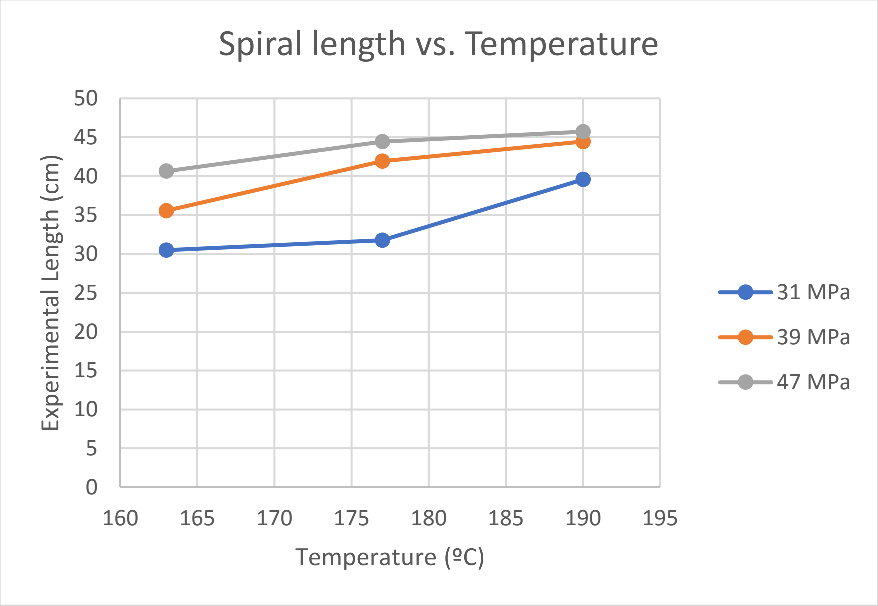


Figure 15. Spiral Length vs. Temperature

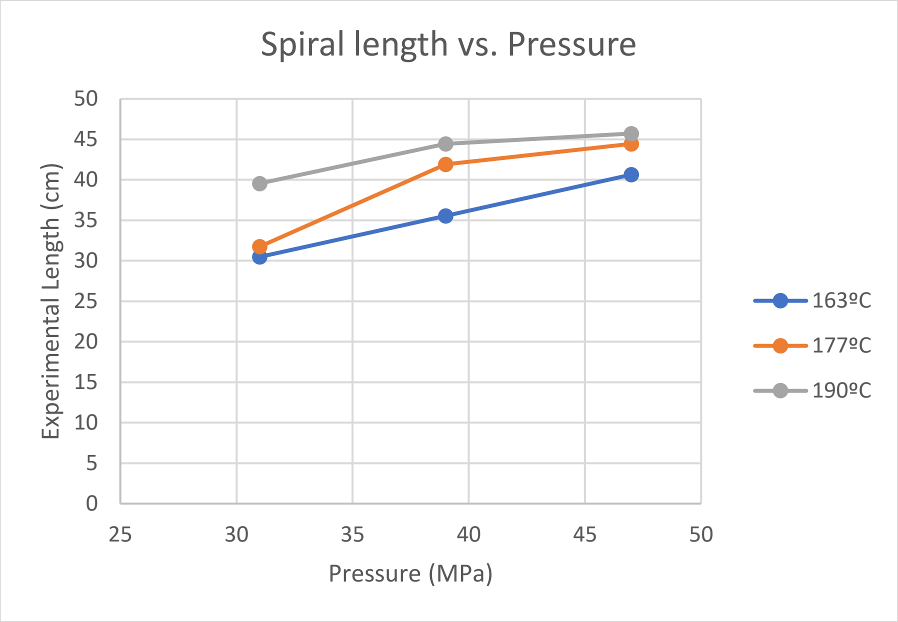


Figure 16. Spiral Length vs. Pressure

It is concluded that pressure has a greater impact on spiral length than temperature. As shown by the two graphs, an increase in temperature lengthens the spiral by approximately two inches for each pressure. Meanwhile, the second graph shows that pressure results in an increase of spiral length by about four inches, proving that pressure has nearly double the impact on the mold length.

3.4 Laser Cutting

A volatile manufacturing process available for this project was laser cutting. To profit from this method as much as possible some research on the topic was done.

The most popular material used for laser cutting was acrylic, a non-expensive, strong plastic. This plastic is cut by vaporizing the solid material by a laser that causes the material to change from a solid phase to vapour.

The machine used had the following characteristics:

- Laser Source: CO2 laser, 30-120 watts
- Work Area: 16" x 12" (406 x 305 mm) up to 40" x 28" (1016 x 711 mm)
- Max. Material Height: 4.5" (114 mm) up to 13.25" (336 mm)

The materials that could be easily found were acrylic and delrin. However, some investigation on the materials that could be used was done with the objective of broadening options.

With the Epilog Fusion I laser the compatible materials were:

- Solid Woods
- Acrylic
- MDF & Plywood
- Cardboards
- Paper / Cardstock
- Cork
- Foam (Polymer types)
- Organic Fabric / Polyester
- Rubber

The vapour emitted from the laser cutting process was highly flammable. For that reason a gentle stream of air blew the vapour away from the cutting area.

3.4.1 Results and discussion

The machine was tested to gain some understanding for the prototypes. First, a design had to be made.

Figure 17. Part Creo design

Once the design was introduced in the machine’s system, the sheet of material was placed inside the its workspace. The part was cut in both acrylic and delrin. The acrylic sheet of material was 1/8” thick while the Delrin sheet was 1/4” thick.

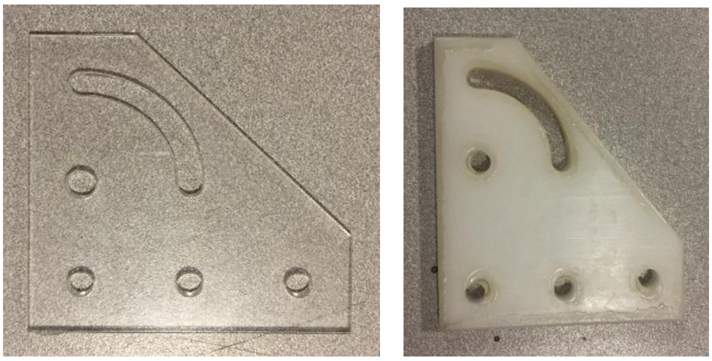


Figure 18. Comparison between acrylic and delrin part

As a result, the acrylic part was not as strong as the delrin part. Nevertheless, the acrylic was much more affordable and took significantly less time than the delrin part.

4. Objectives

4.1 Problem statement

Throwing footballs is hard. As a result, the main objective of this project is to eliminate a current obstacle in order to enjoy everything that comes with playing this sport. To be clear, this product targets different kinds of people:

- Old people: as we advance in age, our muscles become weaker. Consequently, playing football is simply not an option for the elderly. This project idea would allow grandparents and parents to play with their grandchildren and children, no matter their age or physical health.
- Handicapped people: this football launcher is also a good option for handicapped people since their physical disability could be preventing them from playing football. They could be in charge of throwing the football for a team's practice or just for fun. The possibility of participating in a game that they usually watch through television becomes real with this launcher. For this reason, the safety and complexity of the launch system become important features when we target people with disabilities.
- Uncoordinated people: for people whose coordination is a challenge in itself, throwing a football is complicated. This fact should not prevent them from having fun catching the ball.

Apart from the advantages that this launcher brings to certain kinds of people, the fact that it will not need electricity is an important feature. This allows the football thrower to depend only on the user, therefore, it becomes more portable as well as cheaper.

4.2 Project Goals

In order to make the launch system work, there will be research and testing to do focused on two main parts:

Research and testing on the part that will hold the football: the grip. Since this part of the football thrower will also give the ball the spin needed when launching it, a research on different materials and mechanisms is important. Also, the football should be held tight during the launch but should be let free at a particular point in the trajectory. More concisely, our goal is to manage a perfect spin and a design that will allow the football to leave at a certain point.

Research and testing on the launch mechanism. Implementing the trebuchet, the catapult or the compound system in order to throw the ball is one of the existing goals since this football thrower will not use electrical power as its source of energy.

Other equally important goals are aimed towards the system’s design. It is preferable a design that is easy to use and easily understood. On top of that, it would be better if it could be adjustable to different size footballs.

5. Design development

5.1 Ideation

As it was explained in the introduction, the purpose of this project is essentially oriented towards smoothing the small difficulties in life. The objective was to come with an original idea that could be useful as well as challenging to create.

The following ideas were considered: a mobile workspace that can be compressed into a relatively small rectangular shape that a user can carry on his or her back, a mechanical door opener that is activated by using a foot pedal and a mechanical football throwing device.

A SWOT (Strengths, weaknesses, opportunities and threats) was carried for each of this ideas. The football throwing device was chosen after the following SWOT was obtained:

Strengths

- The throwing motion is unique and not seen in any of the popular pre-existing products
- The design has definite practical applications in sports training or recreation

Weaknesses

- The grip that holds the football may fail to release at the correct time, resulting in a poorly thrown ball
- The setup time to launch a football may end up being longer than the time it takes to launch a ball with other products in the market

Opportunities

- There are many aspects of the project that can be iteratively optimizable such as adjustable throw angle/force

Threats

- Producing rotation while launching the football forward to create a spiral will be difficult

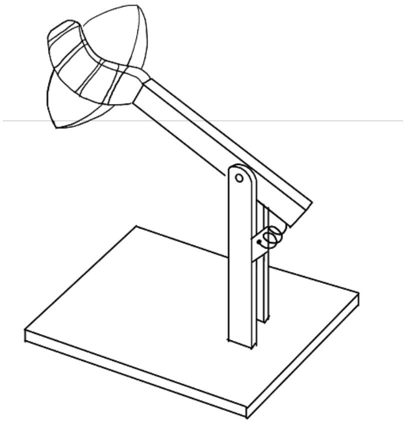


Figure 19. Football throwing device sketch

5.2 Prototype 1

5.2.1 Design description

In order to design the launch system, it was important to experiment first with different ways to give spin to the ball. Only then it would be possible to decide on what movement was necessary for the launch system to make. This characteristic would discard some of the options available.

After researching different mechanisms, it was decided that using a living hinge was the best option. A living hinge, sometimes called a flexure bearing or flex bearing, is a flexible segment of material, usually made from some type of plastic, that joins two rigid surfaces. The hinge is flexible, allowing it to bend. This type of hinge is most often used to join a lid to a container in disposable packaging. 3D printing the living hinge allows multiple changes on it, which is very beneficial for this project where the spin and the grip depend almost entirely on the it.

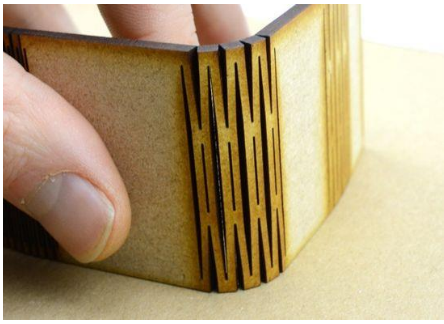


Figure 20. Traditional living hinge

Taking the design of the traditional hinge into account, the following set of hinges were made:

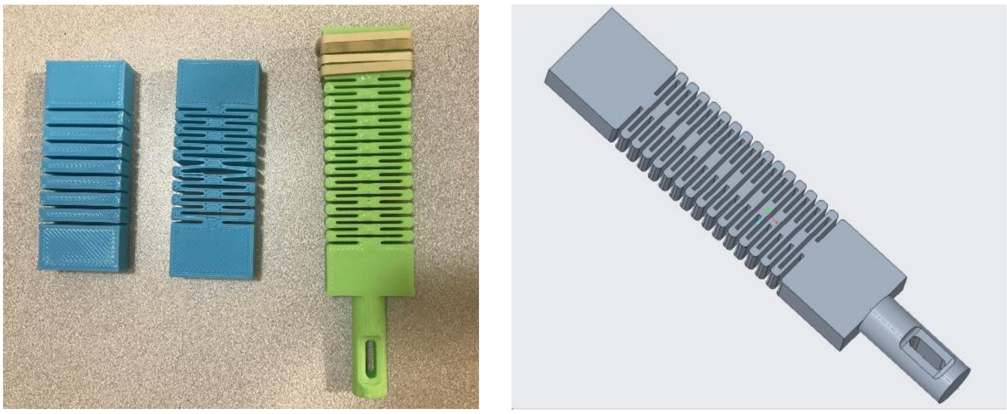


Figure 21. Hinge designs

The first of them had one degree of freedom, which was not as useful as expected. That led to the second hinge with two degrees of freedom. With the new design, the spin given to the ball by rubbing it with the hinge was much better because the ball was able to move more naturally, with no restrictions. The final design for the living hinge was more oriented towards functionality. An extension with a slot was created in order to use it in the prototype.

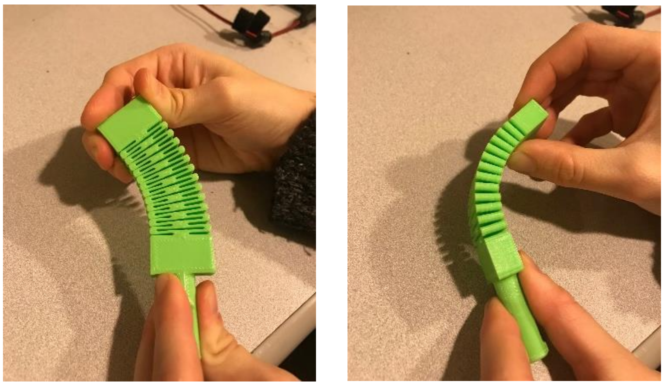


Figure 22. Degrees of freedom on hinge

A very simple prototype was built. The prototype consisted on a wooden board, two living hinges and a wooden stick that prevented the ball from falling. The prototype was launched sideways manually.

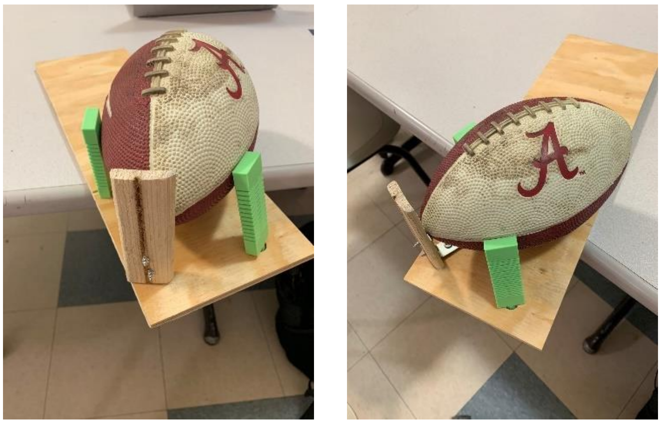


Figure 23. Prototype 1

5.2.3 Advantages and disadvantages

This prototype left a lot of room for improvement. The next prototype would have to be focused on bettering the grip, since the first prototype did not have the ball fixed in place. This was an important point because a requirement for the launch system was a strong grip to transmit as much power as possible.

Fortunately, the living hinge did function as expected. Even though the spin was not perfect, it did give enough friction for the ball to start an acceptable spiral. However, the next design would also have to work towards a smoother one. It was predicted that with a stronger grip, the spin would have to improve.

Last of all, the fact that the ball had to be thrown sideways complicated its compatibility with the launch systems researched. Practically all of the throwing systems needed a vertical launch because they used gravity as a source of energy.

5.3 Prototype 2

5.3.1 Design description

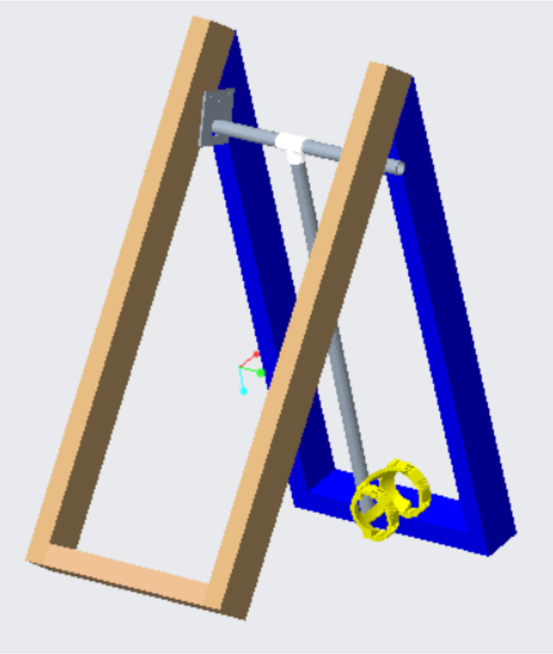


Figure 24. Prototype 2 Creo design

To arrive to this design many steps were needed. First, the living hinge design was enhanced. These changes made were crucial because as it is visible, a new case where the living hinges were attached was designed.

The new hinges were angled so that they could hug the ball and keep it in place. They were also made thicker than the initial design so that they were stiffer. Some holes were introduced in the design so that joining various hinges was possible. By doing this instead of designing a long strip already connected, a lot of support structure was avoided when 3D printing.

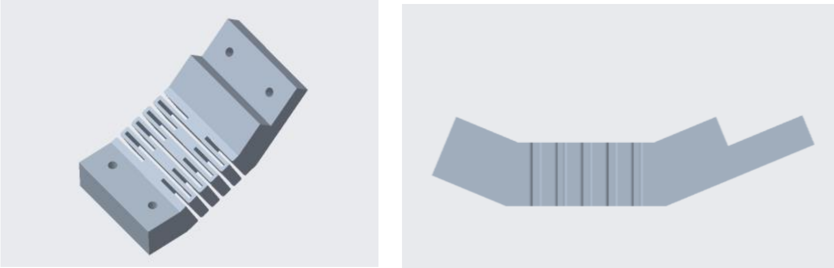


Figure 25. Living hinge new design

The rest of the casing was also 3D printed. The dimensions of a small sized football were taken before making the design and the holes were made taking into account that they had to be compatible with the holes of the hinges. Only the left side of the hinges was connected so that the case could open.

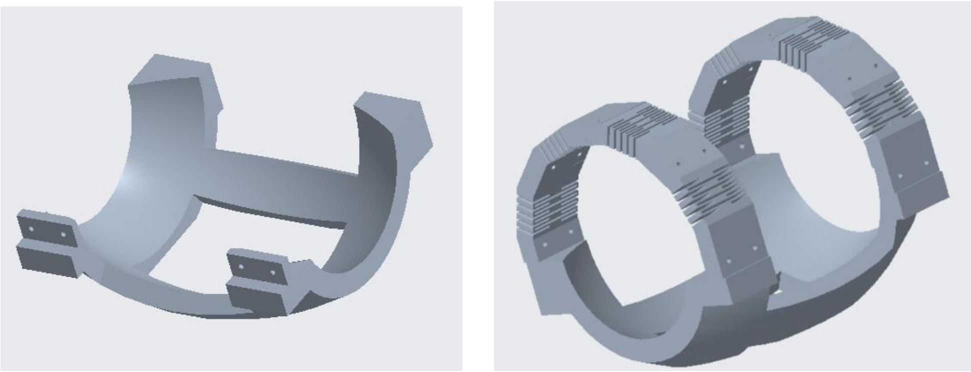


Figure 26. Casing for football with and without hinges

Moreover, a frame with a horizontal PVC tube was built. The casing was also attached to a pole which was then connected to que horizontal tube with duck tape. Laser-cut acrylic was used for the tube’s mount. This can be seen in the following figure.

Figure 27. Prototype assembly

The result can be seen in the following figure. The PVC tube allowed the pole a pendulum movement. The extension of the pole was added so that it could be moved by hand since the launch system was not already in place. Consequently, the quality of the spin was proportional to the power given manually to que whole set.

Figure 28. Prototype 2 final result

It is also visible how some cardboard was added to the end of the hinges. These two pieces of cardboard with a straw connected to a string were the release mechanism. A hole was cut into both pieces of cardboard and the straw was inserted through both holes. This maintained the ball inside the case until the straw was pulled away at a certain point in the football's path.

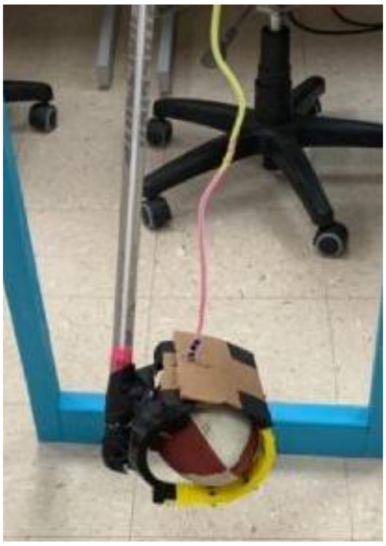


Figure 29. Pin release

5.3.2 Advantages and disadvantages

There are many improvements visible at plain sight when you compare the first and second prototype. The progress made on the hinges and the case were decisive. By creating the new case, it was possible to maintain the ball trapped during the part of the trajectory where the football gains energy, before the throw.

The pin release was not one of the objectives planned for the second prototype, but it became necessary to try out the new design. Even though it was made from cardboard and a straw, it was very successful. The point at which the release system functioned was conditioned by the length of the string connected to the straw. This variable was something to experiment with for the final product.

The frame in which everything rested was also an upgrade. Clearly, the whole mechanism would have been impossible to test if it were not for the frame.

Despite the betterment of the second prototype, there was still space for improvement. The new design had a major weakness: the connections between elements. Due to a tight schedule and a wish to see if the current case for the football could work; the tube, the pole and the case where attached to each other with duck tape. This was a temporary arrangement that affected directly to the quality of the launch as well as the useful life of the prototype. On top of that, the frame was not sturdy enough to endure a powerful throw. As a consequence, resistance and endurance became the main objectives for the next design.

As well as enhancing what was already done, it was also important to brainstorm new features for the upcoming design. One of the main aims would be securing the case to the pole with a connection that permitted adjusting the angle the case made with the floor.

5.4 Final prototype

5.4.1 Design description

For the final prototype, as it was said earlier, the connections between all the elements in the assembly had to be changed. The aluminum pole that intersected the horizontal tube was also changed for another PVC tube to provide consistency but also because it would facilitate its connection. A pipe connector was used between the PVC tubes.

Figure 30. Pipe connector

A new mounting was designed to attach the case to the PVC vertical tube. The design consists on three holes for the screws to join the mounting to the tube, another hole that will act as a pivot between the mounting and the casing, and a circumferential slot for the case to move from one side to another. This can be seen in the next figure.

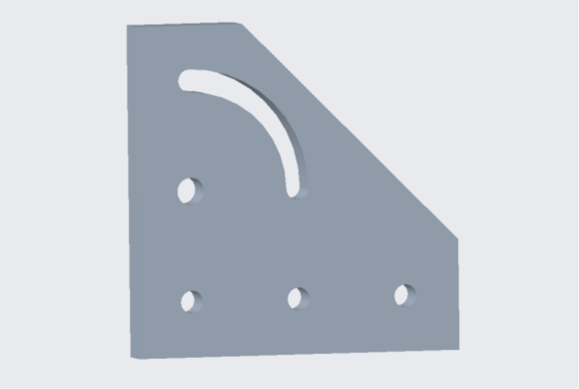


Figure 31. Mounting Creo design

Taking in consideration the functionality of this element in the assembly, it was decided to make it from acrylic since it is a strong plastic. This could be nicely done with laser cut, allowing a smooth surface in the insides of the holes and slots for the angle to be adjusted easily.

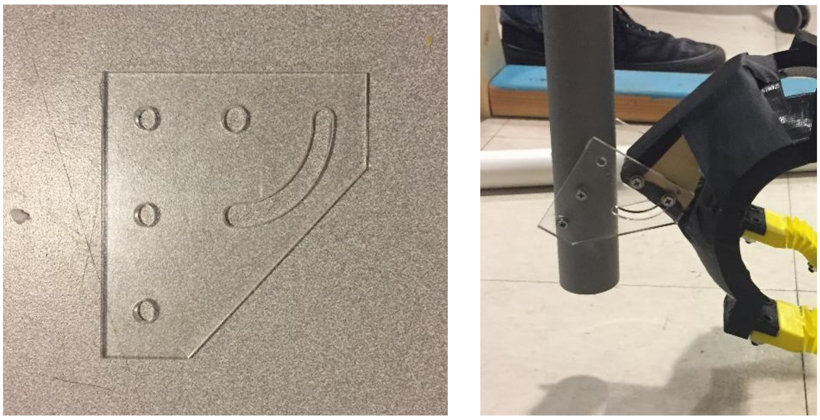


Figure 32. Case mounting

As it can be seen in the figure, only two of the holes to join the mounting to the tube were used. This is because there was not much distance between the pivoting hole and the others, leaving a tight space for the case to rotate. As a solution, the mounting was tilted. Two elements like this were used at both sides of the casing for more strength.

Even though acrylic is a strong plastic, after a few trials it broke. Delrin was used in its place because it has high fatigue endurance, which makes it more expensive. The delrin sheets that were available for this project were thicker than the acrylic sheets. This made it harder for the laser to cut, increasing the cutting time significantly.

It is also important to notice that a wooden block had to be stuck to the old casing so that que mounting could be adhered.

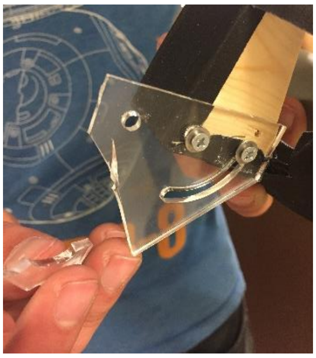


Figure 33. Broken acrylic mounting

Before substituting the broken mounting for the new one, the design was altered so that all the holes could be used, in other words, so that the casing could turn from side to side without crashing into the tube.

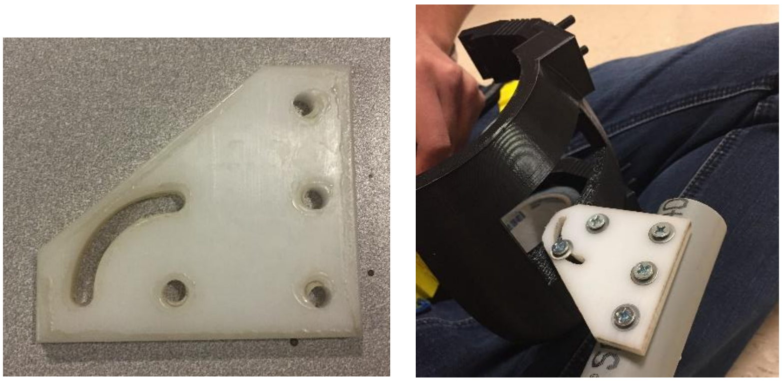


Figure 34. Delrin mounting

The previous frame was completely dismantled and the pieces were reused to build a new sturdier frame. Various horizontal wooden blocks were added to make it stable.

Figure 35. Comparison between old and new frame

The acrylic in the supports for the horizontal tube also broke after testing the prototype numerous times, so they had to be changed for delrin.

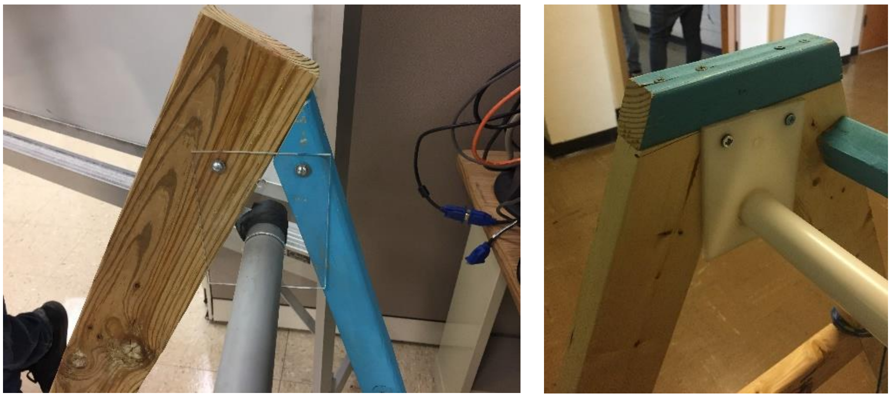


Figure 36. Acrylic vs Delrin mounting

Moreover, the casing and the hinges were improved even more. The previous case did not enclose the football correctly. The edges it had, managed to hamper the exit of the football from the case since they provided additional friction.

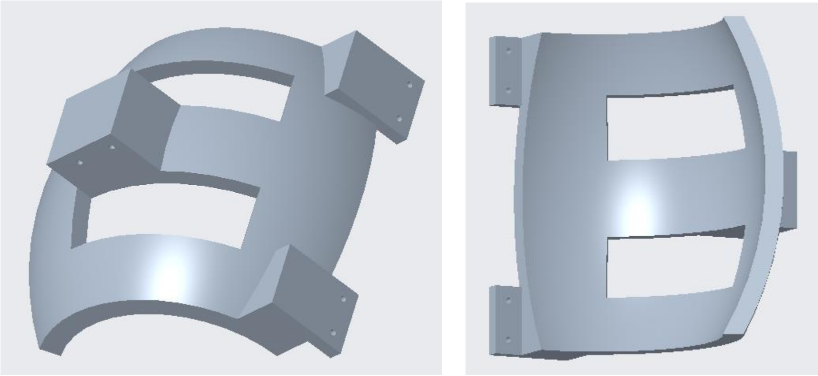


Figure 37. Final case Creo design

For the sake of comparing the previous and current designs, captures of each will be presented side by side.

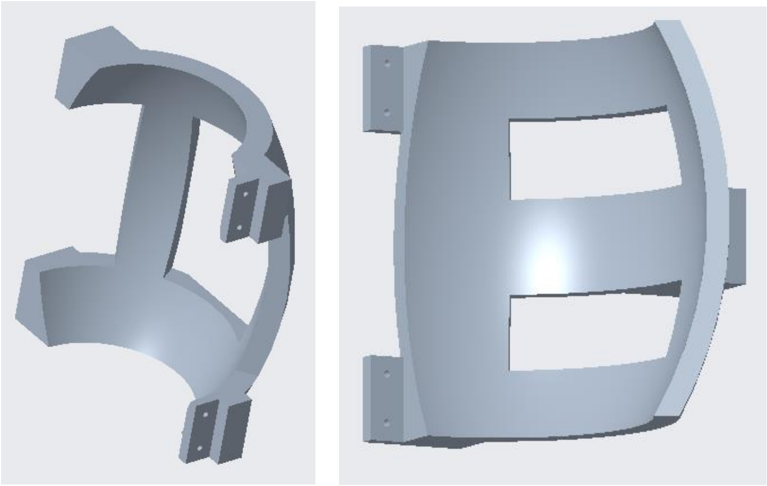


Figure 38. Comparison between previous case (left) and current case (right)

As it can be seen comparing the figures above, que old case had very pronounced edges and in general a more complex design. For the new prototype the edges were smoothed out and opened for the ball to fit comfortably.

Another feature was added to the last design: an extension to attach the mounting to the case without the need of a wooden block. This can be seen in the next figures.

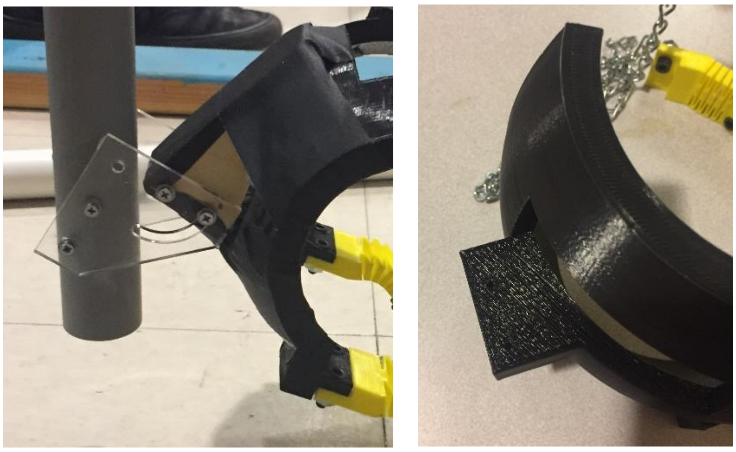


Figure 39. Comparison between wood extension and 3D printed extension

The old casing needed a wood block duck taped to its back so that the mounting could be used, while the new design had it built-in. This improved the endurance of the case significantly and gave a neater overall look for the final prototype.

The hinge used in the second prototype worked perfectly fine but they were made thicker just to experiment with the different stiffness. The resulting design can be seen in the following figures.

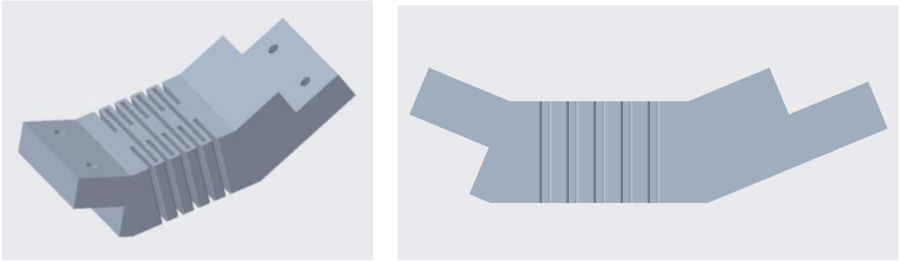


Figure 40. Thicker hinge Creo design

This design, however, was not used for all the hinges because it did not offer the elasticity needed. As a result, a combination of the old and new hinges was used.

The release system was also altered various times as it was made of short-lasting materials. Bearing in mind that one the objectives for this project was being able to use different sized footballs, a chain was used to substitute cardboard. This would permit adjusting the tightness by placing the pin at different holes.

Figure 41. Side view of casing

The figure illustrates how the chains were screwed to the ends of the hinges. Two sets of chains were used, one for each strip of hinges. This set did not work as well as expected, the chains were heavy enough to hinder the football's exit from the case affecting the resulting spin.

Other alternatives were researched. Finally, ropes were used for the pin release. This option still met the requirements to meet the objective of using a wide range of footballs, in other words, adjusting the tightness was possible. However, the biggest advantage of using rope was its light weight.

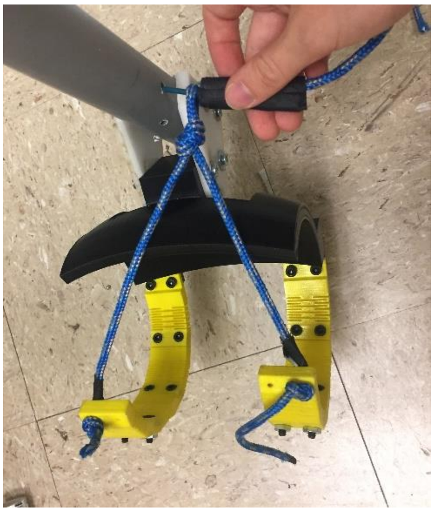


Figure 42. Pin release using ropes

In the figure above it can also be seen that the place where the pin was inserted changed with respect to the last prototype. Instead of placing the pin closer to the ball, the hole was moved to a lateral of the vertical tube. This arrangement improved the spiral of the football noticeably. By changing the pin to a horizontal position rather than the vertical position it had initially, it was easier for it to come out. Earlier, there were some trials in which the straw got stuck in the cardboard, failing to release the ball. Later, this problem was solved with the change in orientation.

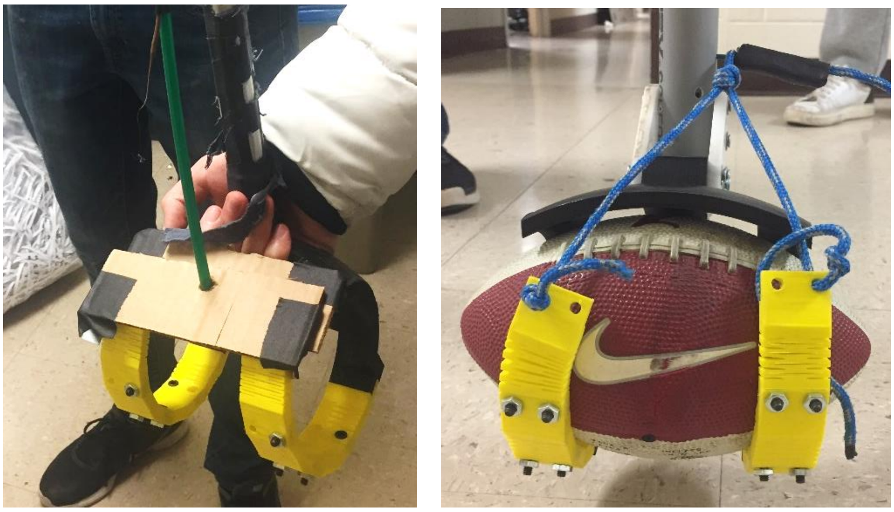


Figure 43. Pin release comparison

An additional difference between the first release system and the last was the pin. For the first prototype a straw was used. For the second prototype a strong wire replaced the straw. The wire was a betterment because its smaller diameter allowed for it to be inserted on the pole. The change in material also meant more resistance to folding and a longer useful life.

Finally, there was another innovation. A spring was integrated so that the mechanism could have a stable source of power. An additional reason to include the spring was that having the football launcher work manually would make it very difficult for disabled people to use it. A 30lb extension spring was used. In order to integrate the spring a wood block and another PVC tube were used. This is shown in the figure below.

Figure 44. Side view of final prototype with spring

5.4.2 Advantages and disadvantages

The final prototype was a significantly improved version of the precedent prototype. Many of the objectives stablished or this design were accomplished. The overall quality of the product was enhanced. This was managed by removing the duck tape and using durable elements like the pipe connectors and the delrin supports. The same was achieved by improving the frame that could now endure stronger throws without stumbling.

A series of release systems were experimented with until arriving to the optimal one. With the new pin release the launch became more consistent because the pin did not get caught during the throw.

Nevertheless, the addition of the spring was not as successful. A different source of energy would have to be researched because the spring did not provide the homogeneous power that was expected from it.

Some of the changes made were also headed in another direction different from the durability of the product. These changes were: the adjustable angle of the casing and the variety of living hinge designs. The aim of this variations was to experiment with them and conclude what was the optimal arrangement for the final product. To be clear, what angle and what hinge combination would imply a better spiral at the moment of release.

6. Design of experiment

The current final prototype has some features that are possible to adjust. Consequently, there is a certain arrangement in which the launch will be optimal. The variables identified during the process were angle of launch, release time and hinge design. It is not known how each of these variables affects the number of defects or which of these variables is most responsible for the process output variation. To better understand the process the DOE will be used.

For this process, it was decided that a 2^3 factorial design would be performed. This means that the three important variables will be examined on two levels each: a low level (-1) and a high level (+1). The next table shows the three variables and their low and high-level values.

Table 5. Variable levels

Variable	Variable description	Low (-1)	High (+1)
X_1	Release time	Late	Early
X_2	Mount angle	Bottom	Top
X_3	Hinge type	Black	Yellow

There are 2^3 test conditions which means eight experiments had to be conducted to collect all the necessary data. The following table shows the variance calculated for the eight experiments. Variance can determine "noise" effects.

Table 6. Variance results

Test	y1	y2	y3	yave	Variance
1	122,03	134,69	113,79	123,5	110,8
2	132,2	138,46	140	136,9	17,1

3	58,53	60	86,74	68,4	252,2
4	30	85,7	53,16	56,3	783,0
5	107,46	117,64	109,85	111,7	28,3
6	107,14	96,42	101,53	101,7	28,8
7	105,26	137,7	109,09	117,4	314,3
8	72	54,54	79,51	68,7	164,1

These results should have been used to select process settings that minimized the output variability, or “noise”. Nevertheless, because of the tight schedule, it can be seen that there was a lot of noise in these experiments’ data. This is because the measurement chosen was spin, therefore, it did not take into account other important parameters.

Another table with the matrix for variance was put together:

Table 7. Design/Calculation matrix

Test	**x1**	**x2**	**x3**	**x1x2**	**x1x3**	**x2x3**	**x1x2x3**	**Variance**
1	-1	-1	-1	1	1	1	-1	110,8
2	-1	-1	1	1	-1	-1	1	17,1
3	-1	1	-1	-1	1	-1	1	252,2
4	-1	1	1	-1	-1	1	-1	783,0
5	1	-1	-1	-1	-1	1	1	28,3
6	1	-1	1	-1	1	-1	-1	28,8
7	1	1	-1	1	-1	-1	-1	314,3

8	1	1	1	1	1	1	1	164,1

With the data from the table the main effects E_1, E_2 and E_3 were computed, as well as the variable interactions E_{12}, E_{13}. E_{23} and E_{123}. The sign of a main effect tells us the direction (causes an increase or decrease in our output) while the magnitude tells us the strength of the effect. The effects were ranked in the following table to better compare them. Their corresponding probabilities were also calculated to make a test of significance for the main effects. The next table with the y-axis and x-axis values was the result.

Table 8. Ranked effects

Rank	**Standard deviation**	**Effect Value**	**Effect**
1	-1,47	-40,75	E2
2	-0,79	-16,06	E23
3	-0,37	-14,97	E13
4	0,00	-14,34	E3
5	0,37	-3,3	E123
6	0,79	3,57	E1
7	1,47	27,09	E12

The next figure shows the normal probability plot of estimated effects versus standard deviations for the sampled data variance of this experiment. A straight line was drawn between the point closest to zero and the adjacent points that gave the most shallow slope. This was done to identify outliers on both extremes. The data points that appear on or near the line should have been considered insignificant, however, it can be seen that the data used was not reliable because practically all noise effects proved to be significant.

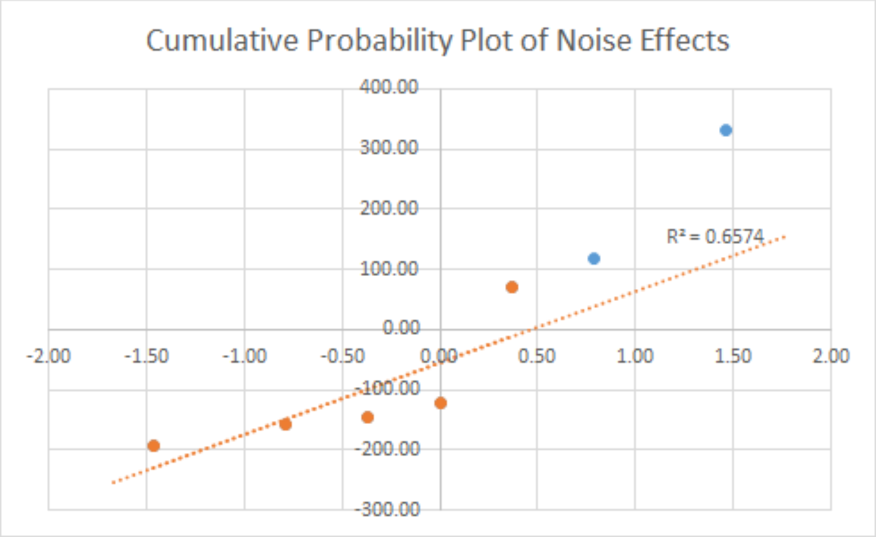


Figure 45. Noise effect values vs. Standard deviation

The estimated effect versus the corresponding standard deviations was also plotted, this can be seen in the next figure. Any effect above the line in the right half plane or below the line in the left half plane had to be considered graphically significant while the effects on the line or near the line were insignificant.

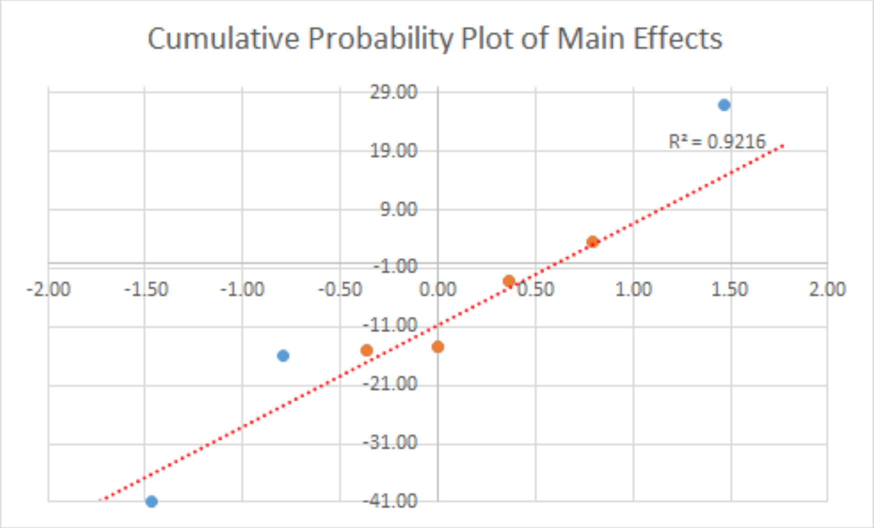


Figure 46. Main effect values vs. Standard deviation

As a conclusion to all this experimentation the optimal settings were: one black, three yellow grip configuration with low mount angle. From the DOE, it was concluded that the mount angle had the most significant impact on the output and variance. Additionally, the combination of the release time and mount angle was another large contributor to the overall output. As mentioned before, this was not the most accurate method for optimizing the thrower as RPM does not perfectly characterize what a good spiral should be. For instance, many of the high mount angle trials received high RPM ratings but from observation, the balls were nowhere near a tight spiral motion but rather tumbling randomly. Therefore, for more accurate results, another output may need to be looked at in addition to RPM such as change in distance of the tip of the ball from its original axis or rotation. Because it was not possible to do this, it was decided to use the observations while testing with the DOE results to obtain the final configuration for the prototype. During testing, it was observed that the black hinge setup with a low mount angle and early release had the longest throw distance with a tight spiral. Since the prototype was designed to be customizable, no significant changes needed to be made.

7. Design for assembly

Assembling a design takes approximately half of the time of the total production period. Decreasing it is a way of decreasing costs, a common interest when manufacturing a product. That is why it is important to know the information of each part of the design and what manufacturing processes it undergoes to help reduce the assembly time.

When the parts are assembled together, handling and alignment times become important parameters. These depend on:

- The way a part has to be grasped: tweezers, tool, one hand, two hands etc.
- How a part is presented: automated dispense, fetching distance, tray etc.
- The size of the part: smaller parts are more difficult to handle as well as large parts.
- Part symmetry: rotation or orientation needed for alignment.

To carry out a design for assembly analysis for the prototype in hand, a table containing a list of the parts was gathered. For each of the parts it was evaluated whether it was strictly required, its rotational symmetries α and β as well as a small description relevant to handling. The rotational symmetry α is about an axis perpendicular to the axis of insertion and the rotational symmetry β is about the axis of insertion.

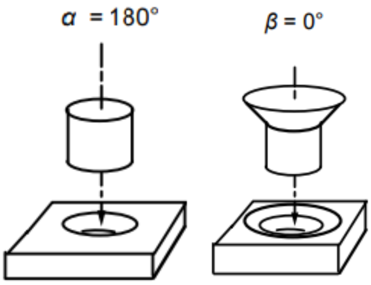


Figure 47. Rotational symmetry example

Table 9. DFA list of parts and specifications

Part Description	**Part Required**	**Alpha (deg)**	**Beta (deg)**	**Part Notes**
Football Casing	1	360	360	View obstructed
PVC	0	180	180	Large
Living Hinges	1	360	360	Align to two medium hole and hold
PVC Casing Mount	0	360	360	Align to 3 medium holes and hold
Wood Frame	1	360	360	Large
Pole Mount	0	180	360	Align to two medium holes and hold
Springs	0	180	0	flexible
Screws/Bolts	0	360	0	Align to medium hole and hold
Washers	0	180	0	Align to medium pin
Rope	1	180	0	Tangle, tie a knot

There are several ways in which the prototype assembly can be improved. One that would have a significant impact is changing the assembly of the living hinges. If the four hinges were able to be manufactured as a single part, the assembly time would be reduced significantly. This change would noticeably reduce the number of bolts and nuts used to assemble the machine, and reduce the amount of total parts.

Another change could be to change how the casing is mounted onto the pole. Currently two different plastic pieces are needed with ten screws to mount to the pole. Since the assembly time for this part is significant, instead of using the current short screws, longer screws that go all the way through the part could replace them. The two plastic parts at both side of the pole could also be connected so alignment is easier.

In general the adjustments that could be made to reduce the assembly time are effortless and could benefit the production.

8. Manufacturing cost

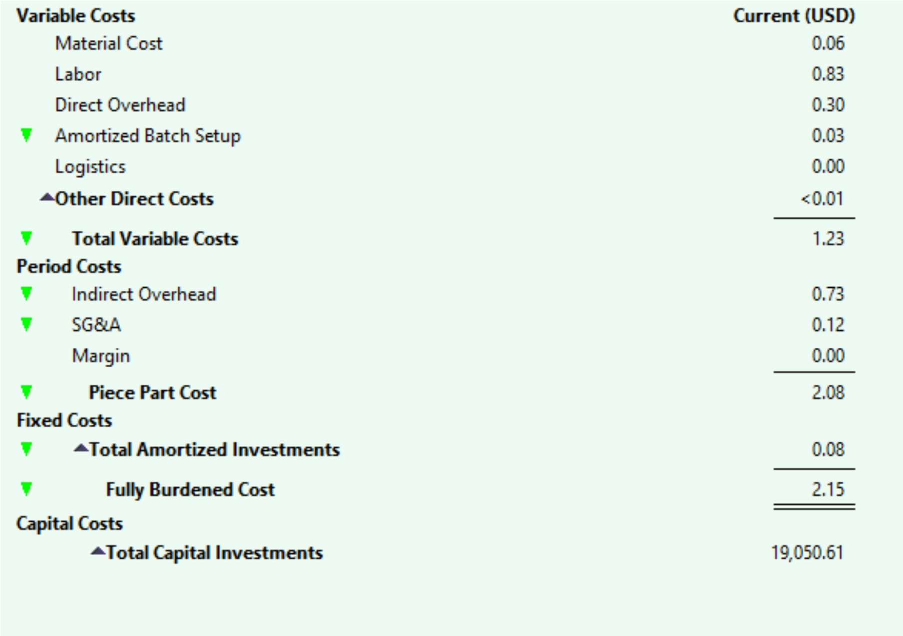
To compute the manufacturing cost, a 10 year plan was stablished. Many materials and manufacturing costs that could be used for the components of this device would be too expensive if it were not for a long-term production life. On top of that, it was simulated that 3000 football launchers would be produced during each year.

The program used for the computation of costs and simulation of manufacturing processes was aPriori, a cost management platform. A table including the materials assigned to each element of the football launch was put together.

Table 10. Part materials

Part	**Material**
Angle bracket	Steel, Cold Worked, AISI 1020
Launch pole	Stainless Steel, Stock, AISI 410
Supports	Stainless Steel, Stock, 15-5 PH
Hinges	Polypropylene Med Impact Copol
Case	ABS, Hi Impact

For the hinges, the process of injection molding was introduced in aPriori. This was done because 3D printing the hinges could take too much time for a long-term production. Polypropylene was chosen because it is a tough, cheap plastic that can be bent without breaking. Since 3000 football launchers were supposed to be made and there are eight hinges per device, 24000 hinges would be manufactured in ten years. The next screenshot of aPriori shows the costs calculated.



Variable Costs	**Current (USD)**
Material Cost	0.06
Labor	0.83
Direct Overhead	0.30
▼ Amortized Batch Setup	0.03
Logistics	0.00
▲**Other Direct Costs**	<0.01
▼ **Total Variable Costs**	1.23
Period Costs	
▼ Indirect Overhead	0.73
▼ SG&A	0.12
Margin	0.00
▼ **Piece Part Cost**	2.08
Fixed Costs	
▼ ▲**Total Amortized Investments**	0.08
▼ **Fully Burdened Cost**	2.15
Capital Costs	
▲**Total Capital Investments**	19,050.61

Figure 48. aPriori screenshot for hinge manufacture

As it can be seen, using injection molding as the manufacturing process would mean an initial capital investment of \$19050 (16707€). However, since there would be 24000 hinges produced per year, the cost per part is as low as \$2.08 (1.83€). It is wise to conclude that injection molding is a good option as long as there is a considerable production.

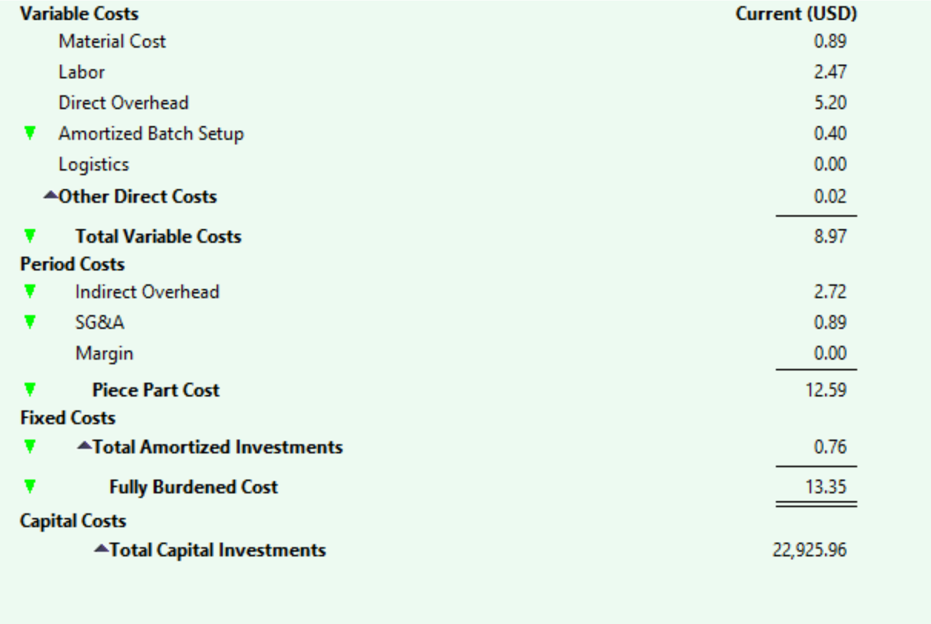
The same was done for the angle bracket, the mounting of the device that permitted changing the angle. Steel was chosen for that part because it is one of he main stress points of the thrower. This was confirmed when it was made out of acrylic and it easily broke. Even though it did not break when it was made out of delrin, steel was a better option because laser cutting the sheet of delrin took a very long time.

	Variable Costs	Current (USD)
▲	Material Cost	0.66
▼	Labor	0.05
▼	Direct Overhead	0.03
▼	Amortized Batch Setup	0.04
	Logistics	0.00
	▲Other Direct Costs	0.02
▼	Total Variable Costs	0.79
	Period Costs	
▼	Indirect Overhead	0.04
▼	SG&A	0.08
	Margin	0.00
▼	Piece Part Cost	0.90
	Fixed Costs	
	▲Total Amortized Investments	0.00
▼	Fully Burdened Cost	0.90
	Capital Costs	
	▲Total Capital Investments	0.00

Figure 49. aPriori screenshot for angle bracket manufacture

Since there are two angle brackets per device, 6000 would be made every year. This helped repay the initial investment on steel, lowering the price per part to $0.9 (0.79€).

The case for the football launcher was simulated to be done by injection molding. Other simulations were also tried but the intricate shape of the case made it too expensive. As a result ABS was used and the costs were the following.



	Variable Costs	Current (USD)
	Material Cost	0.89
	Labor	2.47
	Direct Overhead	5.20
▼	Amortized Batch Setup	0.40
	Logistics	0.00
	▲Other Direct Costs	0.02
▼	Total Variable Costs	8.97
	Period Costs	
▼	Indirect Overhead	2.72
▼	SG&A	0.89
	Margin	0.00
▼	Piece Part Cost	12.59
	Fixed Costs	
▼	▲Total Amortized Investments	0.76
▼	Fully Burdened Cost	13.35
	Capital Costs	
	▲Total Capital Investments	22,925.96

Figure 50. aPriori screenshot for case manufacture

The software did not take into account that the investment on the injector machine was already done because the simulations were done separately. For that reason the total capital investment is $22925 (20099€) which is very high. However, part cost is $12.59 (11.07€) which is adequate.

When the same procedure was done for the launch pole, and the supports, they were both made of stainless steel. A part cost of $14.21 (12.50€) and $6.14 (5.40€) was obtained for each of them respectively. The frame was not used during the simulation because another design had to be thought.

A table with the fully burdened cot of each part was put together to see how much the production of the majority of thee football launcher would cost.

Table 11. Football launcher part costs

Part	**Cost ($)**	**Cost (€)**
Angle bracket	1.8	1.58
Launch pole	14.21	12.49
Supports	12.28	10.79
Hinges	17.2	15.12
Case	13.35	11.73
TOTAL:	$58.84	51.71€

This price of $58.84 (51.77€) is low compared to the existing machines that are around $2000 (1778€). Even though the frame was not simulated, its price could be estimated. If the same stainless steel material used in the supports was used for the frame, taking into account that the machines needed to cut out the pieces and the labor needed to assemble it, a cost of around $40 (35.19€) is estimated. Concluding on a price of $98.84 (86.87€) for the whole product.