COMILLAS
UNIVERSIDAD PONTIFICIA
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GRADO EN INGENIERÍA EN TECNOLOGIAS INDUSTRIALES

TRABAJO FIN DE GRADO

RE-DESIGN FOR MANUFACTURABILITY OF A GARMENT STEAMER

Autor: Álvaro González García

Director: Luis M. Mochón Castro

Madrid

JULIO de 2020

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

RE-DESIGN FOR MANUFACTURABILITY OF A GARMENT STEAMER

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico 2019/20 es de mi autoría, original e inédito y

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El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido

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Fdo.: Álvaro González García Fecha: 03/ 07/2020

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Luis M. Mochón Castro Fecha: 05/ 07/ 2020

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I cannot express enough thanks to the friends that supported me during my exchange year in the University of Illinois at Urbana-Champaign. Despite being in a foreign country for a whole year, you have made it look easy.

Finally, I offer my honest appreciation to my supervisors Leon Liebenberg and Luis Manuel Mochón, for helping me as much as they could and for guiding me until throughout this year.

RE-DESIGN FOR MANUFACTURABILITY OF A GARMENT STEAMER

Autor: González García, Álvaro.
Director: Luis M. Mochón Castro
Entidad Colaboradora: University of Illinois at Urbana Champaign.

RESUMEN DEL PROYECTO

Según un estudio realizado en el año 2017, el 12% de las emisiones mundiales de CO_2 son debidas a procesos de fabricación de productos para el consumo humano. Según los objetivos de desarrollo sostenible es una prioridad reducir estas emisiones para el año 2030, con el objetivo de cuidar el medio ambiente. Con esto en mente, el fin de este proyecto es analizar y plancha de vapor de la compañía ABOX desde su diseño hasta su venta pasando por su montaje para después rediseñar una serie de componentes para aumentar su reciclabilidad y reducir el impacto ambiental tanto de su fabricación como de su descarte. Entre los resultados se ha observado una reducción del coste de producción de cada plancha a consecuencia de haber reducido el número de componentes. Además se eligió un material adecuado para estas nuevas partes que reduce el impacto ambiental de la plancha y facilita su reciclaje.

Palabras clave: Plancha de vapor, Emisiones de CO_2, Manufacturabilidad, Componentes, Ensamblaje.

1. Introducción

Este Proyecto de Fin de Grado se centra en el análisis y rediseño de una plancha de vapor de vestir, un tipo de plancha para ropa que utiliza el vapor de agua como forma de eliminar los pliegues y la propagación de enfermedades y otras infecciones, ya que la ropa puede transmitirlas y causar grandes daños. Este elemento fue elegido debido a la relevancia que tiene en nuestra vida cotidiana. Rara vez vemos un hogar que no tenga un aparato utilizado para el propósito descrito anteriormente. Mientras que muchas personas utilizan la plancha tradicional como una forma de eliminar las arrugas, existe una tendencia creciente a la compra de la plancha de vapor para prendas, ya que los nuevos avances tecnológicos están creando innumerables beneficios, como la reducción del tiempo que se tarda en realizar la tarea o el hecho de que la plancha de vapor nunca está en contacto directo con la prenda, disminuyendo las posibilidades de quemarla.

Con esto en mente llevaré a cabo una investigación del producto, desmontando toda la pieza y analizando cada componente por separado (función, material, proceso de fabricación...). Después decidiré uno o dos componentes o incluso un subconjunto y rediseñaré la pieza para su fabricación, teniendo en cuenta varios aspectos como el coste, el impacto que tiene en el medio ambiente o la reciclabilidad. Luego el nuevo producto será evaluado una vez más para que cumpla con los resultados especificados.

Todo esto se logrará mientras hago el último año de mi carrera en los Estados Unidos. Como estudiante de intercambio, actualmente estoy estudiando en la Universidad de Illinois en Urbana-Champaign. Este proyecto se desarrollará como parte de la clase *ME-270 Design for Manufacturability* que es la clase que ha sido validada para *Tecnologías de Fabricación.*

2. Definición del proyecto

Para realizar el análisis y rediseño de la plancha se necesitará el prototipo. Una vez adquirida la plancha de la marca ABOX, el primer paso es desmontar el producto hasta acabar con cada componente por separado. Se hará un estudio del producto, de la competencia y del mercado y se analizaran las especificaciones técnicas. Tras esto se estimará el coste de fabricación y se creará el Despliegue de la Función de Calidad con el que se escucharán las especificaciones deseadas por los clientes. De esta forma se podrá perfeccionar el producto desde la fase de diseño para satisfacer a los compradores. A continuación se hará una lista con estos requisitos y se rellenará una matriz en la que a partir de unos símbolos e indicaciones se transformarán los requisitos en especificaciones de la plancha de vapor. Una vez analizados los resultados del Despliegue de la Función de Calidad, se describirán las 28 especificaciones del diseño del producto.

Posteriormente se analizarán los métodos de fabricación de cada una de las partes de la plancha y un análisis de diseño de montaje en el que se observarán que piezas pueden ser combinadas entre sí para así poder reducir el número de piezas total. Una vez obtenidas aquellas piezas que se van a combinar, se diseñarán mediante un programa de CAD (CREO Parametrics 5.0 en este caso). Se estimarán los costes de fabricación de estos componentes y se propondrán nuevas ideas para el diseño con ayuda de una matriz PUGH. El siguiente paso será diseñar las nuevas partes combinadas con ayuda del mismo programa de CAD.

El último bloque será realizar un método de diseño del experimento en el que se identificarán variables que influyen en el funcionamiento del producto final y mediante una serie de matrices se verá el impacto de cada una. Por último se compararán la plancha original con la rediseñada utilizando una serie de campos, como son coste, tiempo de montaje e impacto medioambiental y reciclaje.

3. Descripción del modelo/sistema/herramienta

El producto que se va a analizar será la plancha de vapor de la marca ABOX modelo *ABOX Garment Steamer LS-532A.*

Figura: ABOX Garment Steamer LS-532A

Las componentes que se van a combinar son: por una parte el tanque de agua con la carcasa blanca y por otra una carcasa interna gris con un anillo metálico y una sujeción de plástico, como se aprecia en las siguientes figuras de CAD.

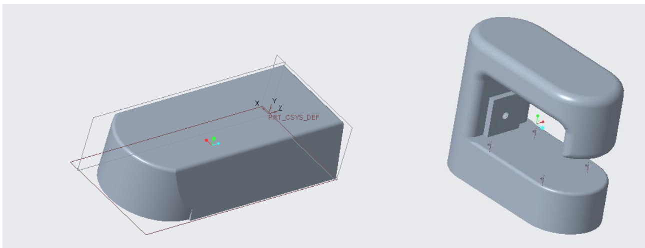

Figura: Tanque de agua y carcasa blanca

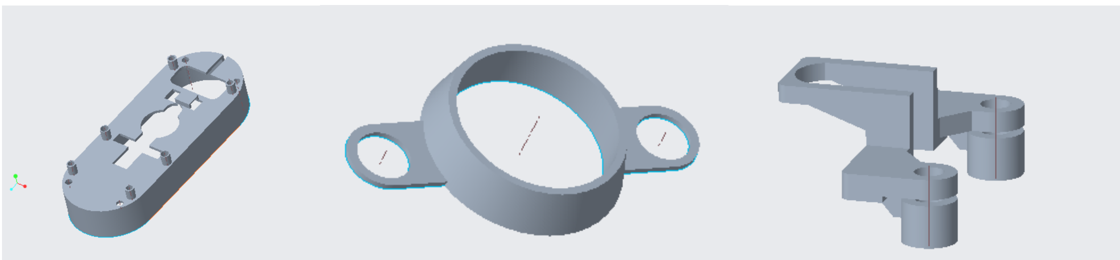

Figura: Carcasa gris, anillo metálico y sujeción de plástico

4. Resultados

Los primeros resultados obtenidos estaban relacionados con las especificaciones del producto y el mercado en el que se encontraba. La siguiente tabla muestra las características de la plancha.

Nombre del producto	**Handheld Steamer**
Modelo	LS-532A
Voltaje	110-120V(USA) 220V-240V(UK)
Frecuencia	60 Hz (USA) 50 HZ (UK)
Potencia	1100W
Capacidad del tanque	90 mL

Tabla: Tabla de especificaciones técnicas

En la sección del Despliegue de la Función de Calidad obtuvimos los requisitos esenciales que tenía que tener según los clientes. Entre los más destacados estaban:

- Bajo coste
- Quite las arrugas
- Sea manejado con facilidad
- No dañe la ropa
- Bonito visualmente
- Se limpie con facilidad

Tras entender los requisitos y focalizar los esfuerzos en áreas determinadas se realizó un Análisis de Diseño para la Fabricación para saber cómo mejorar el prototipo. En éste se llego a la conclusión que lo óptimo era combinar por una parte la carcasa blanca con el tanque de agua y por otra la carcasa gris con el anillo metálico y la sujeción de plástico. Además se analizaron los materiales usados en estas componentes y se propusieron otros dos que podrían realizar la misma función mientras que eran más reciclables y disminuía la contaminación durante su fabricación. Finalmente se decidió que el material óptimo era el PEAD (polietileno expandido de alta densidad)

Tras combinar las piezas el resultado fue el siguiente:

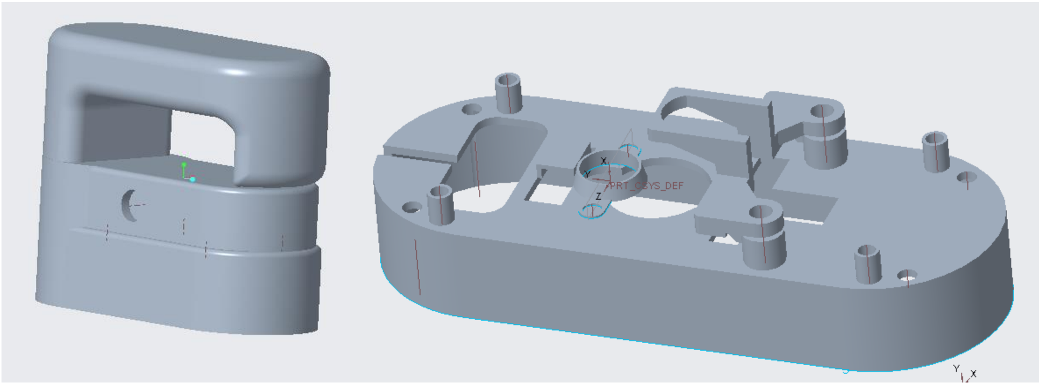

Figura: Nueva Carcasa blanca, y Carcasa gris

En cuanto a los costes, el producto se vende por un precio de 39.99$ en Amazon. Suponiendo que el coste de fabricación sea de aproximadamente el 60% del valor final, da un valor de 23.994$. De esos casi 24 dólares, 8.668 son el coste de las partes originales que se iban a combinar. Tras rediseñarlo y reducir el número de componentes el coste final de estas partes se quedó en 7.233$.

	Carcasa Gris	Carcasa Blanca	Total
Coste original ($)	3	5.668	8.668
Nuevo coste ($)	2.84	4.393	7.233

Tabla: Comparación de costes de las nuevas componentes y las originales

Por otro lado también se logró reducir el tiempo total de ensamblaje de la plancha de vapor. Se estimó que más o menos se necesitarían unos 153 segundos para esta tarea. Al reducir el número de componentes de 15 a 12 este tiempo disminuyó a unos 139 segundos.

5. Conclusiones

Para llegar a conclusiones, se debe analizar la diferencia entre el producto original y el rediseñado una vez encontrados los resultados. En primer lugar veamos los costes (para ello nos basaremos en la tabla anterior de la sección de resultados):

El precio de mercado del vaporizador de prendas de vestir fue de 39,99$ (Sección 2: *Market data and competitors*), el coste de fabricación es de alrededor de 23,994$ (60% del precio de mercado) según lo calculado en la Sección 3: *Manufacturing Cost*. Asumiendo que el coste de las otras partes se mantiene igual, el costo del vaporizador original sin las partes combinadas es:

Coste 1= 23.994 - (3 + 5.668) = 15.326$

Añadiendo el coste de las nuevas piezas:

Costo 2 = 15.326 + 2.84 + 4.393 = 22.559$.

Si se produjeron 20000 unidades, el coste de fabricación de todas ellas fue originalmente:

Coste total de fabricación original = 20000 * 23.994 = 479880$ por año

Dividido por el coste de fabricación del nuevo producto (22.559$):

Nuevo número de unidades = 479880 / 22.559 = 21272.22

En otras palabras, se pueden fabricar 1272 vaporizadores de prendas más cada año sin que varíe el costo total de fabricación. Si la reducción de los costes fuera el objetivo en este caso, el procedimiento sería:

Nuevo Coste de fabricación = 451180 $

Si la compañía quisiera seguir produciendo 20000 unidades al año, el costo disminuiría a 451180$, que es 28700$ menos que antes.

Por otro lado, se dijo en la sección de resultados que el tiempo de montaje se redujo de unos 153 segundos a 139. Partiendo del mismo tiempo, el nuevo número de unidades que se podrían hacer sería:

$$\textbf{Cantidad} = \frac{20000*153}{139} = 22014.39$$

Esto significa que se podrán ensamblar unos 2014 más planchas de vapor en un año utilizando la misma cantidad de tiempo de trabajo.

Pero no solo disminuye el tiempo de ensamblaje y el coste, si no que al cambiar el material a HDPE (polietileno de alta densidad) para las partes modificadas, el producto es más fácil de reciclar y de separar sus componentes para desecharlos por separado. Esto es beneficioso para el medio ambiente. Por otro lado, como el número de componentes se ha disminuido de 15 a 12 hay una reducción en el número de partes del proceso de fabricación, lo que implica menos emisiones de CO_2.

6. Referencias

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Available at: https://www.azocleantech.com/article.aspx?ArticleID=255

RE-DESIGN FOR MANUFACTURABILITY OF A GARMENT STEAMER

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Collaborating Entity: University of Illinois at Urbana Champaign.

ABSTRACT

According to a study conducted in 2017, 12% of global CO2 emissions are due to manufacturing processes of products for human consumption. According to the objectives of sustainable development, it is a priority to reduce these emissions by 2030, with the aim of protecting the environment. With this in mind, the aim of this project is to analyze and steam iron the company ABOX from its design to its sale through its assembly and then redesign a series of components to increase their recyclability and reduce the environmental impact of both their manufacture and their disposal. Among the results, a reduction in the production cost of each iron has been observed as a result of having reduced the number of components. In addition, a suitable material was chosen for these new parts which reduces the environmental impact of the sheet and facilitates its recycling.

Keywords: Garment steamer, CO_2 emissions, Manufacturability, Components, Assembly

1. Introduction

This Senior Design Project is focused on the analysis and redesign of a garment steamer, a kind of clothes iron (also called flat iron) that uses water steam as a way of removing creases and the spread of diseases and other infections, as clothes can transmit them and cause major harm. This item was chosen due to the relevance it has in our daily lives. Seldom do we see a household that does not have an appliance used for the purpose described previously. While many people use the traditional iron as a way of removing wrinkles there is an increasing tendency to the purchase of garment steamer as the new technological breakthroughs are creating countless benefits, such as the reduced time it takes to perform the task or the fact that the steamer is never in direct contact with the garment, decreasing the chances of burning it.

With this in mind I will carry out an investigation of the product, disassembling the whole part and analyzing each component separately (function, material, manufacturing process…). Afterwards I will decide one or two components or even a subassembly and redesign the piece for manufacturability, taking into account several aspects such as cost, the impact it has on the environment or recyclability. Then the new product will be evaluated once again so that it meets the specified results.

All this will be achieved while I do my last year of my major in the United States. As an exchange student, I am currently studying in the University of Illinois in Urbana-Champaign. This project will be developed as part of the class *ME-270 Design for Manufacturability* which is the class that has been validated for *Tecnologías de Fabricación*

2. Definition of the project

The prototype will be needed for the analysis and redesign of the plate. Once the ABOX plate has been purchased, the first step is to dismantle the product until each component is finished separately. A study of the product, the competition and the market will be carried out and the technical specifications will be analysed. After this the manufacturing cost will be estimated and the Quality Function Deployment will be created with which the specifications desired by the customers will be heard. In this way the product can be refined from the design phase to satisfy the buyers. These requirements will then be listed and a matrix will be filled in where, based on symbols and indications, the requirements will be transformed into specifications for the steam iron. Once the results of the Quality Function Deployment have been analysed, the 28 product design specifications will be described.

Subsequently, the manufacturing methods for each part of the iron will be analysed and an assembly design analysis will be carried out, showing which parts can be combined with each other in order to reduce the total number of parts. Once those parts to be combined are obtained, they will be designed by means of a CAD program (CREO Parametrics 5.0 in this case). The manufacturing costs of these components will be estimated and new ideas will be proposed for the design with the help of a PUGH matrix. The next step will be to design the new combined parts with the help of the same CAD program.

The last block will be to perform an experiment design method in which variables that influence the operation of the final product will be identified and through a series of matrices the impact of each one will be seen. Finally, the original plate will be compared with the redesigned one using a series of fields, such as cost, assembly time and environmental impact and recycling.

3. Description of the model/system/tools

The product to be analyzed will be the *ABOX Garment Steamer LS-532A.*

Figura: ABOX Garment Steamer LS-532A

The components to be combined are: on the one hand the water tank with the white housing and on the other hand a grey inner housing with a metal ring and a plastic clamp, as shown in the following CAD figures.

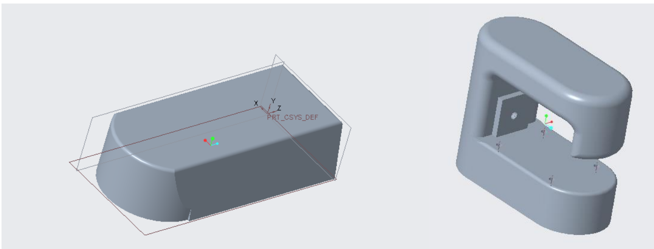

Figure: Water tank and White housing

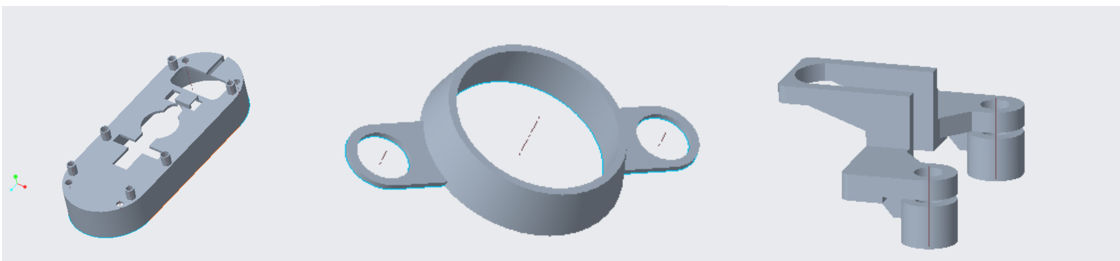

Figure: Grey housing, packing ring and plastic clamp

4. Results

The first results obtained were related to the product specifications and the market in which it was found. The following table shows the characteristics of the steamer.

Product Name	**Handheld Steamer**
Product Model	LS-532A
Voltage	110-120V(USA) 220V-240V(UK)
Frequency	60 Hz (USA) 50 HZ (UK)
Rated Power	1100W
Water Tank Capacity	90 mL

Table: Technical Specifications

- In the Quality Function Deployment section we got the essential requirements that it had to have according to the customers. The most important were:Low cost
- Removes wrinkles
- Easy to handle
- Does not harm garment
- Aesthetically pleasing
- Easy to clean

After understanding the requirements and focusing efforts on specific areas, a Design for Manufacturing Analysis was performed to find out how to improve the prototype. This concluded that the optimum strategy was to combine the white housing with the water tank on the one hand and the grey housing with the metal ring and plastic fastening on the other. In addition, the materials used in these components were analyzed and two others were proposed that could perform the same function while being more recyclable and reducing contamination during manufacture. Finally it was decided that the optimal material was HDPE (High Density Polyethylene)

After combining the parts the result was the following:

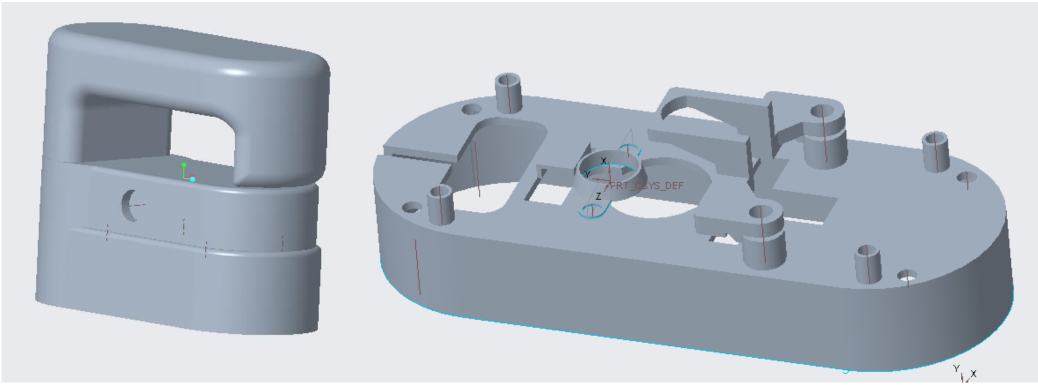

Figure: New White Housing and New Grey Housing

When it comes to costs, the product is sold for $39.99 on Amazon. Assuming that the manufacturing cost is approximately 60% of the final value, this gives a value of $23,994. Of that almost $24, $8,668 is the cost of the original parts that were to be combined. After redesigning and reducing the number of components the final cost of these parts was $7,233.

	Grey Case	White Case	Total
Original Cost ($)	3	5.668	8.688
New Cost ($)	2.84	4.393	7.233

Table: Cost comparison between original and new components

On the other hand, the total assembly time of the steam iron was also reduced. It was estimated that about 153 seconds would be needed for this task. By reducing the number of components from 15 to 12 this time was reduced to about 139 seconds.

5. Conclusions

To reach conclusions, the difference between the original and the redesigned product should be analysed once the results are found. First, let's look at the costs (we'll base this on the table above in the results section):

The market price of the garment steamer was $39.99 (Section 2: Market data and competitors), the manufacturing cost is about $23.994 (60% of the market price) as calculated in Section 3: Manufacturing Cost. Assuming that the cost of the other parts remains the same, the cost of the original steamer without the combination parts is:

Cost 1= 23,994 - (3 + 5,668) = $15,326

Adding the cost of new parts:

Cost 2 = 15,326 + 2.84 + 4,393 = $22,559.

If 20,000 units were produced, the cost of manufacturing all of them was originally

Total original production cost = 20000 * 23,994 = $47,980 per year

Divided by the manufacturing cost of the new product ($22,559):

New number of units = 479880 / 22,559 = 21272.22

In other words, 1,272 more garment steamers can be manufactured each year with no change in total manufacturing cost. If cost reduction were the objective in this case, the procedure would be

New Manufacturing cost = 451180 $

If the company wanted to continue producing 20,000 units per year, the cost would drop to $45,180, which is $28,700 less than before.

On the other hand, it was said in the results section that the assembly time was reduced from about 153 seconds to 139:

Quantity = (20000*153)/139 = 22014.39

This means that about 2014 more steam irons can be assembled in one year using the same amount of working time.

Not only does this reduce assembly time and cost, but by changing the material to HDPE (high density polyethylene) for the modified parts, the product is easier to recycle and to separate its components for separate disposal. This is beneficial to the environment. On the other hand, as the number of components has been reduced from 15 to 12 there is a reduction in the number of parts in the manufacturing process, which means less CO_2 emissions.

6. References

[1] [C2ES] Center for Climate and Energy Solutions "Global Emissions" 2019. Available at: https://www.c2es.org/content/international-emissions/#:~:text=Global%20Manmade%20Greenhouse%20Gas%20Emissions%20by%20Sector%2C%202013&text=Globally%2C%20the%20primary%20sources%20of,72%20percent%20of%2 ll%20emissions.

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Available at: https://www.azocleantech.com/article.aspx?ArticleID=255

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1. DISSASEMBLY OF THE PRODUCT AND BILL OF MATERIALS

As previously stated, for this thesis we will analyse a garment steamer. More specifically the *model ABOX Garment Steamer LS-532A* will be used and studied with detail.

Figure 1: ABOX Garment Steamer LS-532A

The first part of the process is to disassemble the product. The steps taken for this were the following:

1. Removing the water tank.

Figure 2: Step 1

2. Unscrewing main case and separating the bottom part.

Figure 3: Step 2

3. In this step we will remove the wires and other forms of carrying electricity. For this project we will not evaluate the electrical component of the garment steamer. Only the mechanical parts that have required a manufacturing method and are used for protecting, joining, storing… will be studied.

Figure 4: Step 3

4. The bottom part continuous to be divided into smaller sub-assemblies. One of them is the metallic plate with has the ceramic plate attached and its cover that prevents the heat to spread to the upper part of the steamer.

Figure 5: Step 4

5. Moreover, the soleplate has a base which has the function of protecting it while the steamer is not being used

Figure 6: Step 5

The following picture shows all of the parts used to build the product (not including the wires).

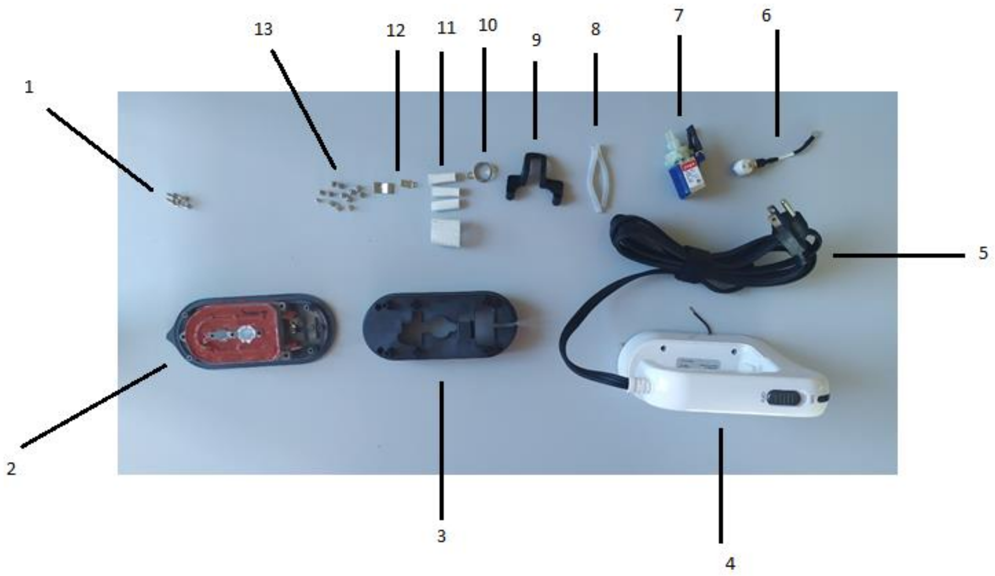


Figure 7: Step 5

Looking at *Figure 7*, each number corresponds to a part or a subassembly

1. Medium size thread screws that held the case and the lower part together. Were removed in *Step 2* (4 units)
2. Ceramic Soleplate: It consists of a thick plate made out of iron that heats up when the steamer starts working and transforms the water into steam (evaporation) and a ceramic soleplate that is placed right between the ceramic plate and the clothes that want to be treated, to prevent the steamer from burning the clothes in case it wants to be used using the flat iron method. The two parts were joined permanently, making it extremely difficult to detach. However, we will analyse them separately, as they are made of different materials and required a totally different manufacturing method.

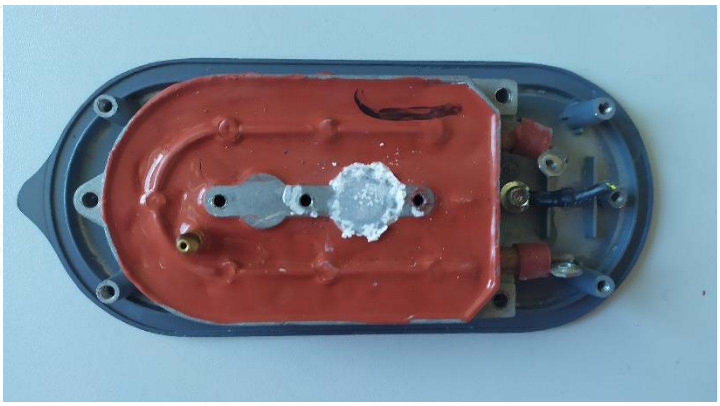


Figure 8: Ceramic soleplate (grey) and iron plate (garnet)

3. This item is a steel protecting case that is placed on top of the iron plate to isolate it from the wires and other vulnerable components that could suffer severe

consequences if the heat was transferred to them. It was joined to the soleplate using 6 screws (part number 13).

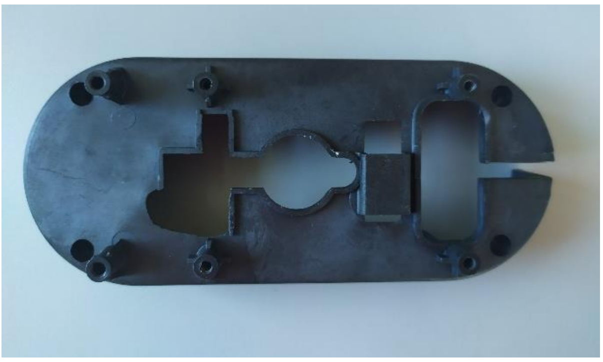


Figure 9: Steel case

4. Plastic white case: it is biggest component and it is used to not only to protect smaller and more delicate parts such as the wires but also to keep everything together. It has attached an indicator light, a power switch and a steam trigger.

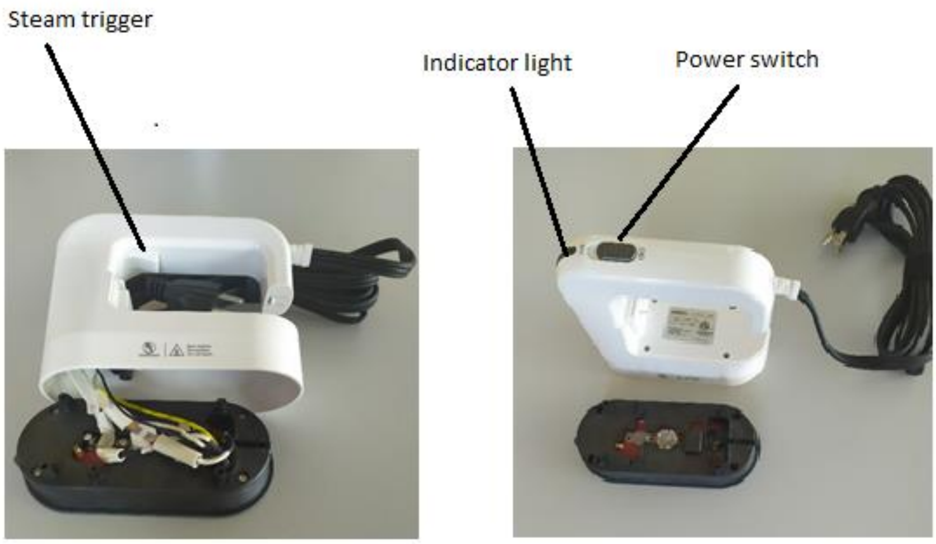


Figure 10: Plastic white case

5. Power cable: used to transmit the power from the plug to the garment steamer, so that the energy is used to heat the water and transform it into the steam the will be later used to remove the wrinkles.
6. Manual thermostat: makes sure the water is at the correct temperature. If it exceeds the desired temperature it will alert the user through the indicator light (*Figure 10*).
7. Water suction pump: Electromagnetic pump that uses a magnetic field set to the right angle to the direction the water moves in. A current is passed through the field, causing the water to move in the desired direction.
8. Protective silicone cases used to cover wires.
9. Plastic structure that serves as a way of keeping the wires together
10. Packing ring that attached the thermostat to the ceramic soleplate.
11. Protective silicone cases used for thicker wires.
12. Small sheet metal parts that joins elements 9 and 2.
13. Small size threaded screws, used to join the ceramic soleplate to the metal case, and the plastic structure to the ceramic soleplate. (13 units).
14. Water tank: is connected to the white case and water is stored inside this component, so it can later be used to treat the garment.

Figure 11: Water tank

15. Base: used to cover the bottom of the garment (see *Figure 6*).

PART NAME
1 Medium Size Screws
2.1 Ceramic Soleplate
2.2 Iron Plate
3 Protective Grey Case
4 White Case
5 Power Cable
6 Manual Thermostat
7 Water Suction Pump
8 Protective Silicone Cases
9 Plastic Structure
10 Packing Ring
11 Protective Silicone Cases
12 Sheet Metal Part
13 Small Size Screws
14 Water Tank
15 Base

Table 1: Bill of Materials

There is a total of 15 different parts in this product (excluding the internal wires). The bill of materials will be completed with different columns such as material or manufacturing process (see part 9: DFMA analysis).

2. TECHNICAL SPECIFICATIONS AND DATA FROM MANUFACTURERS

- ***Technical Specifications***

The product that was chosen for this analysis is the *ABOX Garment Steamer*, being *LS-532A* the product model.

Product Name	**Handheld Steamer**
Product Model	LS-532A
Voltage	110-120V(USA) 220V-240V(UK)
Frequency	60 Hz (USA) 50 HZ (UK)
Rated Power	1100W
Water Tank Capacity	90 ML

Table 2: Product specifications

As we can see this steamer works not only in the United States and other countries using 60 Hz as a frequency and 110V as a voltage, but also in places like Europe where the frequency is 50 Hz and the voltage is 220V.

The steamer can be used both vertically and horizontally. The former position is used when we want the steam generation mode, while the latter is when its purpose is to be a normal dry iron. While using it as a garment steamer, it can reach up to 180ºC (356 ºF) killing almost 99% of bacteria ad mold in the clothes. On the other hand, the dry iron mode keeps the panel to 130-150ºC (266-302ºF).

Weight	**871 Grams (1.92 Lbs)**
Length	15.7 cm (6.18 inches)
Width	6.81 cm (2.68 inches)
Height	13 cm (5.12 inches)

Table 3: Product size

The garment comes with an 8-foot (243.8 cm) retractable cord. Most of the components are specifically designed for this steamer and do not have product specifications. However, there is one part that should be highlighted and that is the water suction pump. The brand is JIAYIN being JYPS-1 the type. It has a voltage of 100-127 Volts and a frequency of 50-60 Hertz. In addition to this it has a power of 9 Watts and it used alternating current to work, being water the only element it can work with. The thermostat functions with a voltage of 125 V and an intensity of 16 A.

The power cable is the model C(UN) HPN E252733 Flexible Rubber Cable. It has a rated voltage of 300V, and the working temperature ranges from 95ºC to 105ºC (203ºF-221ºF). Its size is 16 AWG (3x1.31 mm^2)

Type	Conductor		Insulation	Green Grounding Cond		Overall Diam (mm)	Max.Cond.Resist Ohm/km/20°C
	Size	Construction (No./mm)	Nom. Thick (mm)	Nom. Thick (mm)	Nom. Thick (mm)		
HPN	16AWG/2C	65/0.16	1.14	0.38	0.33	3.9±0.05×7.6±0.15	13.5
	18AWG/2C	41/0.16	1.14			3.5±0.05×6.9±0.10	21.4
	16AWG/3C	65/0.16	1.14			3.9±0.10×10±0.15	16.9
	18AWG/3C	41/0.16	1.14			3.8±0.10×79.0±0.15	21.4
	17AWG/2C	52/0.16	1.14			3.7±0.05×7.2±0.10	16.9
	14AWG/2C	41/0.254	2.03			5.1±0.15×9.1±0.25	8.45
	14AWG/3C	41/0.254	2.03			5.1±0.20×11.3±0.30	8.45

Table 4: General data for cable bype HPN

○ ***2.2 Market Data and Competitors***

The market of the garment steamers is rapidly growing as this product is relatively recent. More and more companies that use to produce only iron are either switching to steamers or combining them into one single item. There are more than four hundred different steamers in the market right now making it an extremely competitive sector.

The major competitors when it comes to garment steamer sellers in the market right now are:

- The best rated garment steamer in the market is the *Conair Turbo ExtremeSteam Handheld Fabric Steamer*. Has a higher power than the *ABOX Garment Steamer*, 1550 Watts. It comes with a water tank of 7.3 Oz of capacity (207 gr).
- The best seller in *Amazon* is the *Hilife Handheld Garment Steamer*. The water tank has a capacity of 8.1 Oz (229.6 gr), having a power of 700 Watts.
- The best value garment steamer is *Conair CompleteSteam Fabric Steamer*. Its main characteristic is how compact it is, being only 9.5 inches tall (24.3 cm). It has a power of 1100 Watts.
- Best garment steamer and iron combination: *Rowenta IXEO All-in-One Iron + Steamer*. Has a power of 1500 Watts and a steam output of 25g/min, with a water tank capacity of 1 Liter.

Product	Price
ABOX Garment Steamer LS-532A	39.99$
Conair Turbo ExtremeSteam Handheld Fabric Steamer	81.99$
Hilife Handheld Garment Steamer	*24.99$*
Conair CompleteSteam Fabric Steamer	30.99$
Rowenta IXEO All-in-One Iron + Steamer	233.48$

Table 5: Competitors and prices

As we can see, the *ABOX Garment Steamer* has an average price in the market. *Rowenta IXEO* and *Conair Turbo* provide a better experience while using the appliance, but at the cost of a way higher price. But these two steamers can be treated as part of the luxury sector due to its high prices, so it is safe to say that they are not really competing against the ABOX steamer, as they are made for two different classes. While the garment steamer that is being analysed in this thesis may have been made for the medium class that has a problem that requires a solution (the need of removing wrinkles out of clothes by using a product that just satisfies the basic needs), the other two are probably directed to the upper class, that wants an extremely good product and do not mind spending more money.

Taking into consideration that ABOX is not a company specialized in steamers (only has one in the market), it is safe to say that the sales volume of the garment steamer is not going to be very high. On the contrary, a company such as Conair focuses on selling garment steamers and have a huge expertise in that area (that has over 12 different steamers available).

Taking into consideration all of this, the current sales volume can be assumed to be of around 15000-25000 units each year. For the production cost section we will take 20000 units as the number of steamers produced. When it comes to market share, it is clear that the ABOX steamer has a little percentage of the total market of garment steamers. After looking up results for garment steamers, I found that there are at least 430 different steamers that are on the market right now. If you add to that the fact that in *Amazon*, the steamer is the number fifty seven in the ranking of best sellers; we can assume that the market share is going to be something between 0.1 and 1 percent of the total.

3. MANUFACTURING COST

The market price of the *ABOX Garment Steamer* is 39.99$, which is the amount of money the buyer has to pay. However we need to find how much was the manufacturing costs of the product. While production costs reflect all the expenses that are involved with a company when it comes to conducting its business, the manufacturing costs are the total costs that are required to make a certain product. This includes the costs of the materials, the costs of direct and indirect labor, and manufacturing overhead. Direct labor is a fraction of the total labor cost that is assigned to each product. To find out what the manufacturing overhead is we must take into consideration all the allocation systems, being one example the hours the machines have been working, the depreciation of the factory assets, wages and property taxes.

All this costs can also be divided into fixed and variable costs. Fixed costs are those that do not increase if the amount of units produced of a certain product is changed. One example is the rent of the machines. On the other hand, variable costs are associated with the number of goods a company produces. If the volume of the production goes up, the variable costs increase. One example of variable cost is the cost of raw materials used in the manufacturing process.

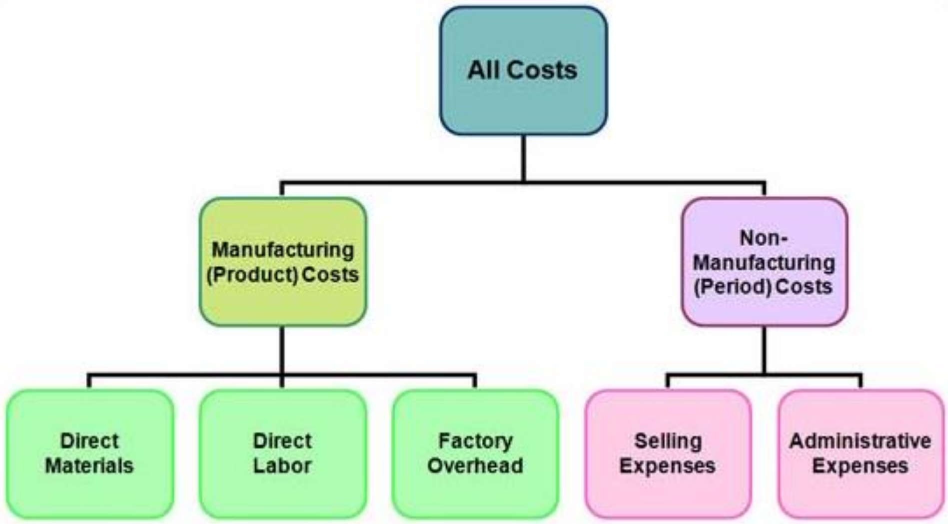


Figure 12: All costs related to a product

Taking into account we can assume that the manufacturing cost can be assumed to be around 60% of the total sales price.

$$\text{Manufacturing cost} = \frac{39.99*6}{10} = 23.994\$$$

This assumption states that all the process of manufacturing the product costs 23.994$, being the remaining the price of the extra expenses and profit for the company.

The next step is to identify where the designers of the product used specific design-for-manufacturability techniques with the aim of improving the cost, quality and function of the garment steamer. First we have to identify what design for manufacturability is. It is a practice used by engineers that consists of designing a product in the best way possible so that it is easy to manufacture, but keeping in mind that it has to have an optimal quality while minimizing the cost.

The following figure shows how important it is for Design for Manufacturability (DFM) to have an early impact on the product. As the design progresses each desired change gets more and more expensive and the impact of the change is significantly reduced. Moreover it is more difficult to implement these changes at late stages of the process. DFM should not be mistaken with Design for Assembly (DFA) which only focuses on reducing the product assembly cost by minimizing the number of operations. DFM is concerned with reducing the overall part production cost by minimizing the complexity of the operations.

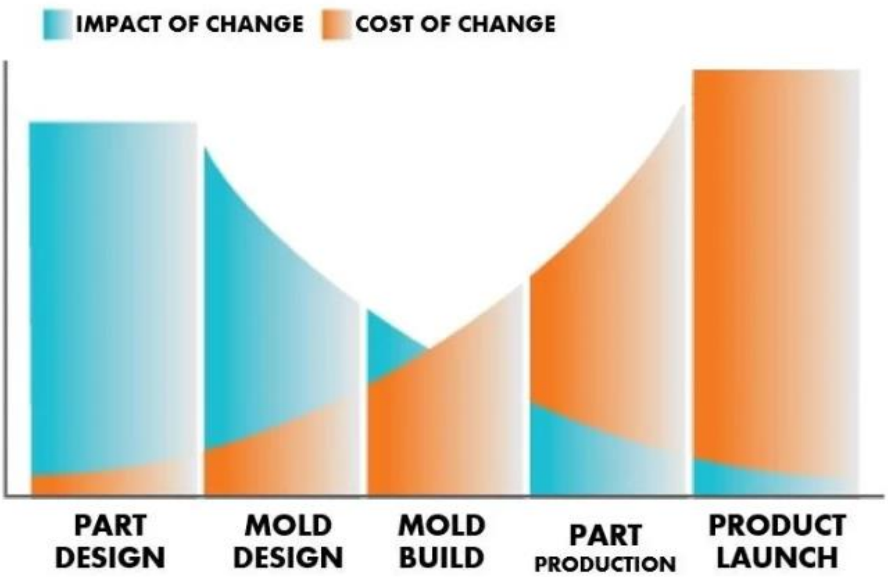


Figure 13: Impact of change and cost of change versus time

There are several design-for-manufacturability techniques involved in the manufacturing process of the garment steamer. The first one is using injection molding as the main manufacturing method for most of the products. As the quantity of garment steamers that are produced is very high, the designing team decided to use a cheap method that is suitable for large amounts of units. If only hundreds of these garment steamers were produced then processes as sheet metal or die casting would be more efficient.

Furthermore, the team designed the product avoiding vertical and thin walls. As injection molding was the main manufacturing process for the components there was a need to come up with a strategy to simplify the production of the parts and the assembly process. The parts made with this method are made by injecting a molten material into a mold and then separated from it. This is why the process of removing the solid part from the mold has to be as easy as possible. By using inclined walls instead of vertical ones you make sure that the part comes out smoothly. In addition the walls have to be thick enough to have the best surface finishes.

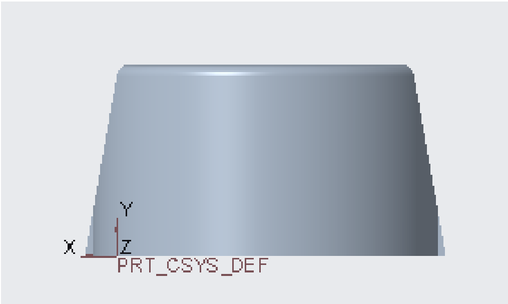


Figure 14: Inclined walls used for the water tank

Moreover, designers avoided pointy corners and edges. As can be seen in *Figure 14*, the corners have been rounded. This helps with the extraction of the part from the mold, as these nodes are the critical areas and are more prone to fail.

When it comes to improving the function of the garment steamer, the designing team tried to reduce the number of parts in order to simplify it. Too many components for one single item can increase the difficulty of assembling the parts, as a worker will not have enough space to operate. This garment steamer has only a few big parts (water tank, white case, grey case and ceramic soleplate), making it a simple design.

Another technique is using off-the-shelf components, in those cases were it costs more to design a part than to buy it to someone else. This is the case with the water pump. Having to design it from scratch and to manufacture it takes more time and money than to buy it from another company, as it is a complex item that requires of electromagnetic knowledge. Technicians that have expertise on that area should be hired, increasing the cost of the final product.

4. QUALITY FUNCTION DEPLOYMENT (QFD)

A quality function deployment, also known as QFD, is a process driven by customers used as a method of planning products, by defining the user’s needs, expectations and requirements and transforming that into a set of ideas and specific plans to design and manufacture the products. It is a way of listening to the voice of the customer and it has a huge importance, as they are the sector that will purchase the product and if they are not satisfied then the whole product is a failure.

It consists of four different phases each one related to one part of the product development process:

1) Product definition: We will collect the Voice of Customer (VOC) and we will translate their needs and demands into specifications that our product has. For this we will use the competitor's information, in order to see in which areas our garment steamer has weaknesses, and in which has strengths.
2) Product development: during this phase the critical parts are identified as well as assemblies and sub-assemblies. We will then evaluate all the characteristics of those parts and we will find specifications that work well for it. Finally, for each functional level we will state the proper requirements.
3) Process development: the manufacturing processes are designed during this phase, including the assembly.
4) Process quality control: Some specifications will be tested before launching the product, inspecting, and controlling all the parts of the process. Its critical parts must be identified.

With this process we ensure that the product that comes out is actually what the customers are looking for. This way, instead of building a prototype and then discarding some parts or redesigning the product, which leads to a high loss of final profit, all the requirements are heard in first place and the garment steamer is adapted so that it meets these criteria.

Collecting customer inputs and applying them to the product and the development process can lead to an increase in the teamwork, as it is a cross-functional activity. It can make sure that the whole company involved in the making of the garment steamer is working with a goal that is the same for everyone, which is the satisfaction of the user. It is also very important to prioritize those things that are more relevant to the customer. Although he might be asking for several attributes that the product has to have, not all of them have the same weight. By prioritizing those that are important, the company is making sure that the satisfaction levels are going to be high.

The following table shows the QFD.

Number of Customer Needs	1 = Weak Impact 3 = Moderate Impact 9 = Extreme Impact	Customer Importance Rating	Weight(gr)	Length(cm)	Width(cm)	Height(cm)	Life Span(Years)	Cost($)	Steaming Time (s)	CO2 Emissions (Kg CO2)	Number of Parts	Water Tank Recharge Time (s)	Hardness(Rockwell)	Steam temperature (ºC)	Failure Rate(%)
	Direction of Improvement for the Technical Descriptors U/D/N														
	Number of Technical Descriptors		1	2	3	4	5	6	7	8	9	10	11	12	13
1	Easy to use	5	3	3	3	3			3		1	1			
2	Lightweight	3	9	1	1	1					3				
3	Durable	4	3				9		1		1				9
4	Low Cost	5					1	9							
5	Low Carbon Footprint	4					3			9					
7	Not Harmful to Garment	4							3					3	
8	Good Resistance to Impact	3	1										9		
9	Recyclable	4					1	3		1	3				1
10	Small Size	2	3	9	9	9					1				
11	Easy to Disassemble	2		1	1	1					9				
12	Successfully Removes Wrinkles	5						9	3					9	
13	Quick	4						3	3			9		3	
	Importance		63	38	38	38	57	114	58	40	50	41	27	69	40
	Target Values			15	5	10	5	40	20	1	13	10	100	180	0,1

QFD Template — Technical Specifications

Table 6: QFD

The customer needs that have been identified are: easy to use, lightweight, durable, low cost, low carbon footprint, not harmful to garment, good resistance to impact, recyclable, small size, easy to disassemble, successfully removes wrinkles and quick. When it comes to the technical specifications, the product characteristics were divided into: weight, height, length, width, life span, CO2 emissions, steaming time, number of parts, water tank recharge time, hardness, failure rate and steam temperature. The next step of the process was to establish how relevant the technical specifications are to the customer requirements. The criteria have been divided into three different grades. If the specifications have a weak impact on a certain requirement then the number 1 has been assigned to the cell that links the two. If the impact is moderate then the number 3 has been chosen and finally if the relationship between the two variables is very strong then the most suitable number is 9. For instance, weight has a moderate impact on easy to use (3) but on the other hand it is really relevant to lightweight (9) and barely has an influence on good resistance to impact (1).

Moreover, a column of customer importance rating has been added right next to the technical descriptions. A number from 1 to 5 has been assigned to each customer requirement, depending on how important each description is to them. While some of them like small size are not of upmost importance (2/5), others such as low cost or how successful it is removing wrinkles are aspects that users are looking for when purchasing the product (5/5).

To calculate the results, a row has been added at the bottom of the chart and it is called *Importance.* It is the sum of the numbers assigned to a certain technical specification multiplied by the importance it has to the customers. For instance, to calculate the importance of the weight:

IMPORTANCE= 5*3+3*9+4*3+3*1+2*3=63

In addition to this row, another one has been included called target values, and meaning the desired value that the technical specification has to have, or in other words, the optimal value. For example 0.1 would be the wanted fail rate for the garment steamer.

Now we will have to develop a correlation matrix for the thirteen technical specifications listed in the quality function deployment. For every pair of specifications we will analyse if the correlation is: strong positive (++) if the two variables have a huge degree of correlation, meaning that when one increases the other one does too, positive (+) if the correlation is a little bit smaller or negative (--) if when one variable has its value increased the other variable decreases.

	1	2	3	4	5	6	7	8	9	10	11	12	13
1		+	+	+		+			+				
2	+					+							
3	+					+							
4	+					+							
5								+			++		--
6	+	+	+	+					+				
7								+		+		+	
8					+		+					+	
9	+					+							+
10							+						
11					++								
12							+	+					
13					--				+				

Table 7: Correlation Matrix

For instance, looking at *Table 7* we can see that weight and height have a positive correlation, as if the height increases, the weight will most likely increase too. Moreover, life span and hardness have a strong positive correlation, as these two factors are very dependent on each other. On the other hand, if the fail rate increases the average life span goes down, meaning there is a negative correlation between these two variables. In addition to this, it is obvious that the correlation matrix is going to be symmetrical, as the impact the variable 5 has on 8 is the same that 8 has on 5, for example.

Competitors have to be taken into account, in order to see in which fields they struggle and in which they are strong. This information is essential so our product can be designed so that it meets the customer's requirements that others do not. We will compare the *ABOX Garment Steamer* with the two competitors that have a similar price (*Hilife Handheld Garment Steamer* and *Conair CompleteSteam Fabric Steamer*. Numbers from 1 to 5 will be assigned to each steamer depending on how well they perform in that area (1 is worst and 5 best).

	1	2	3	4	5	6	7	8	9	10	11	12	13
ABOX	4	3	5	4	5	3	5	3	3	4	5	5	4
HILIFE	3	2	4	3	4	5	3	4	5	4	4	3	4
CONAIR	3	4	4	3	4	4	3	4	4	4	3	4	4

Table 8: Competitive Analysis

More or less the three products satisfy the requirements that the customers have. However, there is a lot to improve for all three steamers. Focusing in our garment steamer, the areas in which it does not meet the needs of the users are mainly: cost (number 6) as it is 15$ more expensive than *Hilife* and 9$ more expensive than *Conair*, but does not give that many advantages compared to the others; CO2 emissions (number 8) as taking care of the environment by manufacturing products with a low carbon footprint is one of the most common requirements right now, as citizens are more and more conscious about how hard we have to work to save the planet from climate disasters. One way to solve this is lowering the CO2 emissions during the manufacturing process, but another one in which we are going to focus is changing the materials used to produce the components so that the steamer is more easily discarded once its working life has come to an end. In addition to this we will look for materials that can be recycled and that have a minor impact on the ecosystem during their production and assembly.

5. CUSTOMER REQUIREMENTS

This section is closely related to the previous one (QFD). We will create a list of customer requirements but including subjective phrases and statements instead of objective values, numbers or metrics, like in the previous section. These statements will then be transformed into a set of design requirements, which will help the designing team to have clear thoughts of what the customers really need and what they really desire. Aesthetics will also be considered, as it is a very important part of the product, which in many cases is the reason behind the customer buying it, as it is pleasing to their eyes. All these requirements will be added to the QFD as new rows. The list will be made up of the five most important subjective requirements that are:

- Smooth finishes and pleasing design: Aesthetics are one of the most important characteristics of any product. Even if a certain product works perfectly and meets all the customer’s demands, if the designing team is not capable of transmitting those features into a good looking design, the sales are not going to be as high as expected. This can be avoided by spending more time in the designing process, taking care of small details like having smooth finishes and features that are pleasing to the eye.
- Correct use of colours: related to the previous point, coming up with colours that suit the product and look good with the design. Moreover some colours might be important to the way the product works. As the garment steamer reaches high temperatures when it is used, it is preferable to use light colours for the outer part so that the interior does not reach even higher temperatures.
- Easy to recycle: due to climate change and the actual situation that the world is in, people are developing a sense of consciousness towards it, being aware of how important it is to take care of the planet we live in. This is why it is requested that the products are easy to disassemble into smaller parts and that they are easily discarded and separated depending on the material, so it can be reused.
- Does not slide on surfaces: most of the times this garment steamers stops working after having an accident, in which it falls to the ground and stops functioning properly. Therefore, having surfaces that do not slide is the best solution for this case, so the garment can be placed anywhere without it sliding.
- Easily cleanable: this is another reason behind the malfunctioning of the product. Dust and other particles accumulate in the interior and leads to a failure of some parts. This requirement is closely related to the number of parts the garment has, as reducing its number will probably make it easier for the user to clean it.

These are the five requirements that the customers care about the most. However, the next page shows the list with all the requirements.

Customer requirement -- Importance

1. Cleanable

   1.1 Smooth surfaces……………………………………………………………. 5

   1.2 Watertight………………………………………………………………….. 6

2. Size

   2.1 Lightweight…………………………………………………………………. 5

   2.2 Easy storage………………………………………………………………… 6

3. Aesthetics

   3.1 Aesthetically pleasing………………………………………………………. 8

   3.2 Colours……………………………………………………………………… 4

   3.3 Ergonomic design………………………………………………………...… 6

4. Stability

   4.1 Does not slide……………………………………………………………. 7

   4.2 Able to stand on its own……………………………………………………. 8

5. Cost

   5.1 Low cost…………………………………………………………………….. 9

6. Temperature

   6.1 Temperature can be controlled with switch………………………………. 7

   6.2 Heats and cools in a short amount of time………………………………... 8

   6.3 Reaches high temperature………………………………………………… 7

   6.4 Temperature is uniform across soleplate………………………………….. 7

7. Comfort and manipulation

   7.1 Can be handled easily……………………………………………………….. 8

   7.2 Long power cable…………………………………………………………. 6

   7.3 Water tank can be easily filled…………………………………………… 5

6. DIRECTION FOR IMPROVEMENT

For this section we will complete the QFD. The direction for improvement is a row beneath the thirteen technical specifications that states whether these specifications have to be maximized, minimized, or require of a certain target that is the optimal value. If it has to be maximized a black arrow pointing upwards will be assigned, if it has a target a white dot will be assigned and if it has to be minimized a lack arrow pointing downwards will be assigned.

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

Figure 15: Direction for improvement key

For instance, we would like to minimize the failure rate (number 13) as we want the least amount of defective parts as possible. On the other hand we want to maximize the life span (number 5) and we want the hardness (number 11) to be a determined parameter, so that it is not too hard or too soft. With this in mind the direction of improvement row will be the following:

	1	2	3	4	5	6	7	8	9	10	11	12	13
D.O.I	▼	▼	▼	▼	▲	▼	▲	▼	▼	▼	O	▲	▼

Table 9: Direction for improvement

The next step is to calculate the difficulty of accomplishment for every technical specification, meaning how hard it is to achieve the expected result (from 0 to 10). Moreover we also need to find out what the relative weight is for every one of them. As we already have the total weight or importance (see *Table 6*), the relative weight is calculated by dividing each weight by the sum of all the weights (will be a percentage).

	1	2	3	4	5	6	7	8	9	10	11	12	13
D.O.A	3	2	2	2	5	6	3	7	5	1	4	2	3
R.Weight	9.36	5.64	5.64	5.64	8.47	16.9	8.6	5.94	7.43	6.1	4	10.25	5.94

Table 10: Difficulty of accomplishment and relative weight

In order to improve the design as much as possible, it is important to focus on a couple of key areas. Therefore we must identify those design requirements that have a higher importance, in other words, which physical changes that we can do to our product will have major relevance in the final outcome. According to the customers, the three requirements that they are looking for in their garment steamer are:

- Successfully removes wrinkles: In the end the main purpose of a steamer is to get rid of the wrinkles that are in your garment, so finding a product that meets these criteria is essential for the users.
- Low cost: Not everyone can afford an expensive steamer, so a huge percentage of the buyers are looking for a product that does the task as efficiently as possible but having the minimum price possible.
- Easy to use: using a garment steamer is a task that sometimes may be difficult and these days the appliances are getting more and more complicated, as they incorporate many new features that are intended to increase the experience , but that also increase the difficulty of understanding how it works.

On the other hand, there are some designing specifications that are more important the others, as can be observed in the QFD. The three with utmost importance are the following:

- Cost: this specification is closely related to one of the customer requirements and to other specifications. Other aspects have to be taken into account to minimize the cost of the whole product; like the length, width or height if more material is used the final cost is going to go up. Moreover the designing team should also acknowledge specifications such as materials or the number of parts in order to reduce the total production cost.
- Steam temperature: it may not seem like a very relevant specification at first, but is closely related to how successful the steamer is at removing wrinkles and also to how much time it takes to iron the clothes. Moreover it has an impact on how easy using the garment steamer is. Although the user must be more careful if the steamer reaches higher temperatures, it is more efficient removing wrinkles.
- Life Span: Even if a product does its job it is not worth buying if it is expected to last for a short period of time. Products that break easily or stop working short after being bought usually have bad reviews and the sales related to that item drop. Therefore, the designing team should put all their effort into developing a product that removes wrinkles as good as possible but also has an adequate life span.

7. QFD FINDINGS

- ## *7.1 FINDINGS*

The QFD helped us have a better understanding of what the customers want for the product that they are going to purchase. Not only did we find which specifications are more important but we also found out some aspects that should be mentioned:

- ✓ By developing a correlation matrix we discovered how these specifications were related between each other. This can help while designing the product as we can predict how a change in one specification will impact another one.
- ✓ The difficulty of accomplishment showed us how realistic it is to achieve a certain specification. This way we can focus more on the ones that have higher chances of being successful. However we must also take into account the importance each of them has. If a certain specification has a high difficulty of accomplishment but it also has a huge importance to the product then it is worth taking the time and the risks to focus on that area. For example cost (number 6) has a 6 on difficulty but hast the highest importance out of all. On the contrary length, width and height are easy to accomplish but the relevance they have is also low.
- ✓ Using the customer requirement weights and predicting the impact each specification had on every requirement we were able to compute the importance or weight of each specification, meaning how relevant they are to the final design. Specifications with a bigger weight should be prioritized over the ones that have a low weight. Relative weight helps us see how each specification contributes to the total weight.
- ✓ The competitive analysis showed what the strengths and weaknesses of the competitors are. By comparing our steamer to other two ones on thirteen different aspects we can observe which specifications we should improve for our product and which ones are fine.

- ## ***7.2 IMPROVEMENTS***

With this in mind, the next step is to identify areas to concentrate our design effort, using design for manufacturability techniques, in order to improve the market share. First of all, we should identify the requirements that are more important for the customer. Being easy to use, removing wrinkles successfully and having a low cost appear to be the requirements that users care about the most. The steamer is pretty advanced when it comes to removing the wrinkles accurately, so it is an area that will not be improved as much, but still requires a great amount of effort. Therefore, the design should concentrate on cost and easiness to use. The former can be improved by changing the material used or reducing the number of components.

By designing the product se that it has less parts we can cut down on the manufacturing costs of the whole steamer. For instance, if we are using injection molding for two components and we design one that can serve the same purpose as the previous two, we do not need one of the molds anymore, which is most if the injection molding cost, as the material is usually cheap.

Furthermore, reducing the number of part might also have an impact on how easy the steamer is to use. Products with many components usually require of technical knowledge and may be confusing. In addition to this, if the parts that are combined are internal parts, it decreases the difficulty of disassembling it. This might come in handy when there is a problem with a steamer and it stops working. The user might have the need to disassemble the steamer and try to fix it, so having the least amount of necessary parts is a clear advantage.

Moreover, and although this specification was not in the QFD as it was not countable and we could not establish a target value for it, recyclability is of utmost importance. Not only because the environment needs it, but because customers are more and more aware of how important it is. This can be achieved by changing the materials used for the parts, and using those that can be recycled easily. Also, reducing the number of parts (which was also stated in the last paragraph) would facilitate things when it comes to discarding the product.

8. PRODUCT DESIGN SPECIFICATION (PDS)

For this section, a comprehensive Product Design Specification (PDS) will be developed, listing all 28 trigger points for the new model and the manufacturing process that has been proposed. Keeping all these specifications in mind the design will be developed trying to meet this criteria.

- **Safety:** This is one of the most important bullet points. The garment steamer must cause no harm to the user while doing its task. The main problem is the high temperatures that the product reaches, causing major burns if in contact with the customers skin. A protective case should be available and a clear indicator that the ceramic soleplate is currently hot and should not be touched.
- **Standards:** As this product is commercialized worldwide by Amazon, it must have standards that meet the criteria of most of the countries. Quality and safety standards should be clearly stated in a guide that will be given to the user and the designing team should work towards improving the environmental standards as much as possible.
- **Product life span:** the time interval when a product is sold to the user to when it is discarded should be maximized. This was related to one of the customer requirements which had one of the highest points in importance, so choosing the right materials and designing the product so that it lasts as much as possible is vital.
- **Materials:** The main materials that are used to build the garment steamer and plastic, silicone, iron and metal. These materials should be chosen wisely in order to improve the products performance but at the same time meet other needs like improving the recyclability.
- **Ethics and society:** The developers of the product should avoid any kind of controversy when it comes to ethical issues and society. This can be achieved by following certain ethical rules and codes of conduct in order to design the product so that it is not harmful to the user, not offensive (avoid any attributes that might possibly offend someone) and so that its purpose is mainly satisfy the customer’s needs and not only make a profit.
- **Quantity:** Considering that this item can be sold from many online platforms such as Amazon, EBay (and available in not only USA), its original website… and also at many local stores in the United States, we can estimate that the number of units is high, around 20000.
- **Manufacturing facility:** ABOX depends on many different manufacturers to produce their parts. If the quantity of units produced increases then ABOX could start producing most of the parts for themselves, reducing the amount of costs as they would not have to pay other businesses. However, there are some parts that need to be bought to another company as they require technical expertise. This is the case with the water pump that uses electromagnetic fields to function. It might be more

expensive to train employees about this and make it on your own that buying it from another company.

- **Competition:** as garment steamers are becoming more and more popular, there are many competitors for this product. It is ABOX's task to improve the garment steamer and differentiate it from the competitors so that customers choose their garment steamer over others.
- **Packaging:** as there are some fragile components, packaging must ensure that the product gets to the customer in optimal conditions. However, there have been no complaints about the actual packaging, meaning that the current packaging might be satisfactory.
- **Target product cost:** as the product has been sold on Amazon and EBay for more than one year and the price has not changed we can assume that the 39.99$ is the right target product cost. We would need more information about the manufacturing process in order to estimate the ideal price.
- **Shipping:** ABOX can ship the garment steamer to most of the major countries in the world with and additional cost. Moreover, websites such as Amazon and EBay also have shipping to most parts of the world.
- **Environment:** this is currently by far one of the most important specifications. The steamer must be easily discarded and recycled and should leave the smallest environmental footprint possible. There are no complaints about this product not being bad for the environment. However, there are features that can probably still be improved.
- **Life in service:** this product is considered very efficient and works as expected. It has a rating of 4.3 out of 5 in Amazon and 4.2 in Best Buy. Although it can be improved, it is a very good rating and shows that customers are pretty happy and satisfied with the purchase.
- **Performance:** its main purpose is to remove wrinkles and to treat the garment nicely, not harming them as much as a traditional iron. As stated in the previous point, customers are satisfied with its performance, as it was carefully designed for this.
- **Shelf life:** none of the components that are part of the garment steamer are perishable, meaning that they are not likely to die or decay as time goes on. The garment does not have batteries and works connected to a current (the batteries would be perishable). Therefore, this product does not have any problems with being in stock for a longer period of time than necessary.
- **Maintenance:** this item does not require to be checked very often in comparison to others. However it is recommended that the user should check for internal failures and notify an expert if it is a major one. Buttons and joints should be lubricated every once in a while and the water tank should be cleaned regularly in case the water comes with impurities or TSS (total suspended solids)

- **Timescales:** it is unknown how much time it takes for the company to produce and assemble the product. When it comes to transporting the product, it depends on how far the customer is. As the item can be shipped all over the world, the shipping time will vary. The office is in Texas and the company is American, so it will take longer if the steamer has to be shipped to countries further away from USA.
- **Size and weight:** this steamer is already very compact in comparison to other steamers and irons. It is very suitable for handheld operations and can easily be transported. A large amount of them can be shipped at the same time, as the box in which it comes is relatively small. When it comes to weight, it is not very light for its size, but that is totally normal as most of the weight comes from the ceramic soleplate and the iron soleplate that heats up. Both components are necessary for the steamer.
- **Market constraint:** the major market constraint for this product is competitors. As the market for steamers is rapidly growing there are many companies that are starting to produce them. Therefore each one has to constantly develop new features that differentiate their product. When it comes to regulations or turbulence there are no constraints for this.
- **Processes:** there are many processes involved in the production of the steamer. The main manufacturing processes are injection molding, machining and sheet metal forming, which will be explained later. Moreover the designing process and the assembly are worth mentioning due to their relevance.
- **Testing:** we can assume that the steamer was tested successfully, as it has been in the market for more than one year and the reviews on Amazon up to today are really good.
- **Disposal:** it is easy to discard when it comes to throwing the whole product away, as it is quite light and compact. However, if the customers want to disassemble it in order to recycle each part separately (what should be done as not every component is made out of the same material) he will have a hard time, because the steamer is not easy to disassemble.
- **Intellectual property:** the garment steamer is definitely an intellectual property. It belongs in some way to the designing team and the manufacturers as they have put the effort and time into making the product. However they have chosen to sell it, meaning that it becomes a property of the buyer.
- **Quality and reliability:** for the price the steamer has, the quality is adequate. There are other competitors that sell expensive garment steamers, as they provide a better quality and other features. However, our product is cost-effective and provides what the user wants for that price.
- **Aesthetics:** it is very pleasant to the eye. It has a unique design and is different to the traditional irons that customers often see. Moreover the colours are well chosen and it is aesthetically appealing. The finishes are well achieved and the surface gives a feeling of smoothness that gives a good first impression.

- **Company constraints:** the garment steamer is not the only product ABOX has on the market. The company has products related to health, fitness, beauty and home appliances meaning they are focusing on several sectors at the same time. Although there are no obvious intentions of interfering with the profitability of the steamer, it would be better for the steamer's benefits if the company just made this product. Employees would be more specialised and they would achieve greater developments.

- **Customer:** every detail of the garment steamer has been developed and tested to satisfy the needs of the customers. This can be shown on the great reviews it is receiving in websites such as Amazon, in other words, users are happy with what they have bought.
- **Ergonomics:** as stated before the steamer is very compact, making it very easy to handle and carry. Furthermore, the handle it has is comfortable and suitable for the user's hand and all the buttons are placed so that you can reach them with the same hand you are using to grab the steamer, just by moving the thumb.

9. DFMA ANALYSIS

The next step is to perform several analyses, in order to find new concepts and ideas of elements that can be changed or improved. First we will have to upgrade the bill of materials, adding columns for every part with the fields: material, manufacturing process, weight and number of items.

- ***MANUFACTURING ANALYSIS:***

PART NAME	MATERIAL	MANUFACTURING PROCESS	WEIGHT (Grams)	NUMBER OF ITEMS
1.Medium Size Screws	Low-medium Carbon Steel	Machining	2	4
2.1 Ceramic Soleplate	Ceramic	Casting + Annealing	144	1
2.2 Iron Plate	Iron	Iron Casting	103	1
3. Protecting Grey Case	Iron	Iron Casting	63	1
4. White Case	Plastic	Injection Molding	85	1
5. Power Cable	Thermoplastic/ Copper	Annealing +Cabling	60	1
6. Manual Thermostat	Plastic	-	7	1
7. Water Suction Pump	Pllastic + Metal	-	15	1
8. Protective Silicone Cases	Silicone	Silicone Rubber Molding	4	2
9. Plastic Structure	Plastic	Injection Molding	20	1
10. Packing Ring	Steel	Metal Injection Molding	5	1
11. Protective Silicone Cases	Silicone	Silicone Rubber Molding	5	4
12. Sheet Metal Part	Steel	Sheet Metal Fabrication	3	2
13. Small Size Screws	Low-medium Carbon Steel	Machining	1	13
14. Water Tank	Plastic	Injection Molding	15	1
15. Base	Plastic	Injection Molding	20	1

Table 11: Complete Bill of Materials

The total weight of the garment steamer is around 1.2 pounds, or 550 grams. We will briefly explain now the main manufacturing processes, as they are relevant for this project.

- Machining: manufacturing process in which a material is cut into a desired shape and size by removing material with other controlled tools. It is mainly used for metals, but also works for plastics and even ceramics and glass. It has a good dimensional accuracy and surface finish. Moreover, the initial investment cost is lower than other methods, excluding 3D printing. However, it is not the optimal method for high production, and it is very wasteful, as all the material removed has to be discarded (in some cases it can be recycled and reused).
- Injection Molding: manufacturing process in which molten material is injected into a mold. The main advantage is that the material can be melted repeatedly if the outcome is not the required and that the cost is low. Requires a large initial investment in some cases to produce the molds, but after that the injection molding process is quite inexpensive.
- Sheet Metal Fabrication: manufacturing process in which metal is formed into thin sheets. The thickness of the part is considerably below that of its length and width. The most common materials are low-carbon steel, brass or aluminum. This process is characterised for being inexpensive, very fast and ductile (easy to form).

○ ***DESIGN FOR ASSEMBLY ANALYSIS (DFA)***

In order to carry out the DFA analysis we will add four columns to the bill of materials previously shown in *Table 2*. Each column will answer to one different question and for every part we will answer that question with a YES or a NO.

1. Can the part potentially be combined with any of the previously assembled parts because it can be made from the same material? It is obvious that in order to combine two different components into one they have to be made out of the same material. If one is made out of for instance glass and another from plywood there is no possibility of reducing the number of parts.
2. Can the part potentially be combined with any of the previously assembled parts because it does not move with respect to any o the other parts? The relative movement of two different parts requires them to be manufactured separately to enable them to freely move. Only rigid parts can be joined. This also applies to the parts that have to be separated as a part of the usage of the product.
3. Can the part potentially be combined with any of the previously assembled parts because it is not required to be separate to allow assembly of an internal part or parts? If other parts have to be assembled between the parts a space is required to facilitate the process.
4. Can the part potentially be combined with any of the previously assembled parts because there is an alternative fabrication that could be feasibly or economically adopted? We have to take into account if the combination of several parts is logical and can be achieved by a fabrication process that is achievable. In addition to this, the cost of this new assembling process has to be reasonable. Even if it meets all the

requirements stated in the other questions, it is not a viable solution if the budget increases by a great amount.

If the answer to all of these questions is YES then there is an opportunity to combine or eliminate a certain part. If the answer is NO to at least one of the questions then the component is necessary as it is, not being able to be modified or eliminated. We will then observe how many of them are part of the minimum amount of components that the garment steamer has to have. This change in the design might come with a change in the tools needed to manufacture the parts, for example new molds. For the new table, although the columns were to be added to the right side, the columns 'material', 'manufacturing process', 'weight' and 'number of items' have been removed to leave more space for the questions.

PART NAME	Question 1	Question 2	Question 3	Question 4
1.Medium Size Screws	NO	NO	NO	NO
2.1 Ceramic Soleplate	YES	YES	NO	YES
2.2 Iron Plate	NO	YES	YES	YES
3. Protecting Grey Case	YES	YES	YES	YES
4. White Case	YES	YES	YES	YES
5. Power Cable	NO	YES	YES	NO
6. Manual Thermostat	NO	YES	YES	NO
7. Water Suction Pump	NO	YES	YES	NO
8. Protective Silicone Cases	NO	YES	YES	YES
9. Plastic Structure	YES	YES	YES	YES
10. Packing Ring	YES	YES	YES	YES
11. Protective Silicone Cases	NO	YES	YES	YES
12. Sheet Metal Part	YES	YES	YES	YES
13. Small Size Screws	NO	NO	NO	NO
14. Water Tank	YES	YES	YES	YES
15. Base	YES	NO	NO	YES

Table 12: Bill of Materials with questions

As we can see looking at Table 3, the parts that meet all the requirements are:

- 3. Protecting Grey Case
- 4. White Case
- 9. Plastic Structure
- 10. Packing Ring
- 14. Water Tank

The number of parts that can be eliminated or combined is five. On the other hand there are parts that are essential to the garment steamer, being 10 the 'Theoretical Minimum Number of Parts'. The new ideas regarding the combination of parts are the following:

- ✓ Instead of having a removable water tank (*Figure 11*) that attaches to the main structure (white case, number 4 in *Figure 7*), the water tank would be part of the main structure and would just have one hole in order to fill it with liquid. This water tank would also be connected to the water pump, which is located under the protective grey case, with a plastic tube.

- ✓ The plastic structure and the packing ring that were used to hold the cables in place could be designed so that they are a part of the protective grey case. We would then eliminate two parts and would have only one serving the purpose of the three. Moreover, the material used for the grey case could be changed to some king of hard plastic with properties so that it can resist and protect all the elements in the inside. This would make the part cheaper and would make it easier for the three elements to combine, as they would be made of the same material.

10. CAD MODELLING OF THE EXISTING PRODUCT

Using CREO Parametric 5.0, software available for the University of Illinois students, we will CAD model the original parts .As stated before, the parts that are going to be combined are the white case with the water tank and the grey case with the packing ring and the plastic structure. More detailed pictures for each part can be seen in Annexes A to E.

- Water tank:

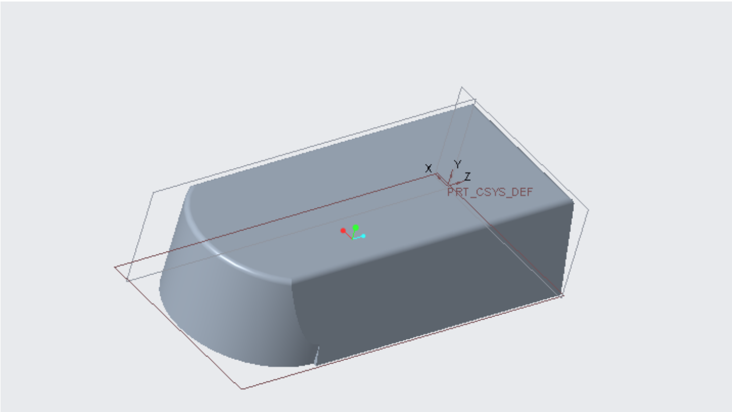


Figure 16: Water tank

- Packing ring:

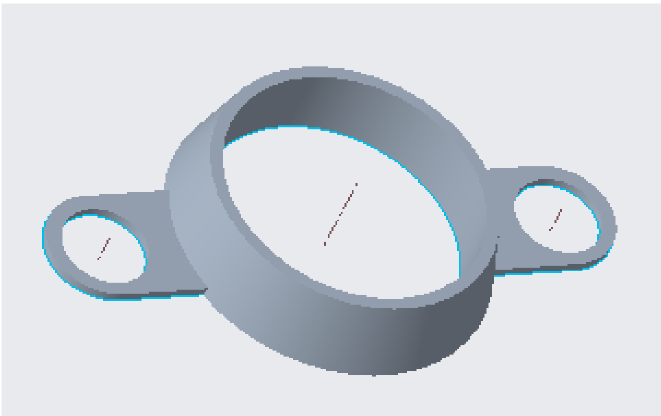


Figure 17: Packing Ring

- Grey case:

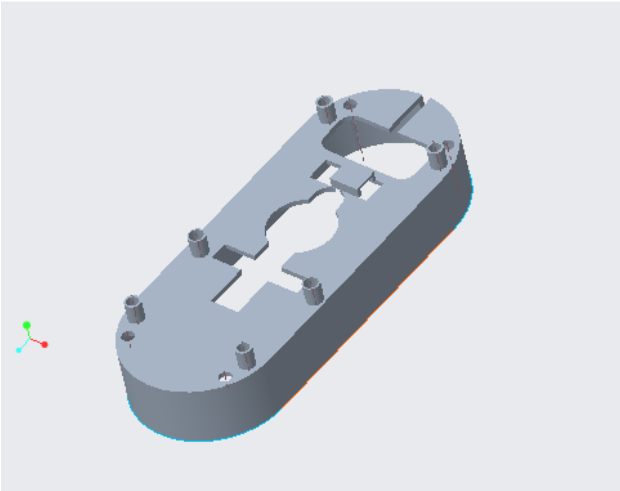


Figure 18: Grey Case

- White case:

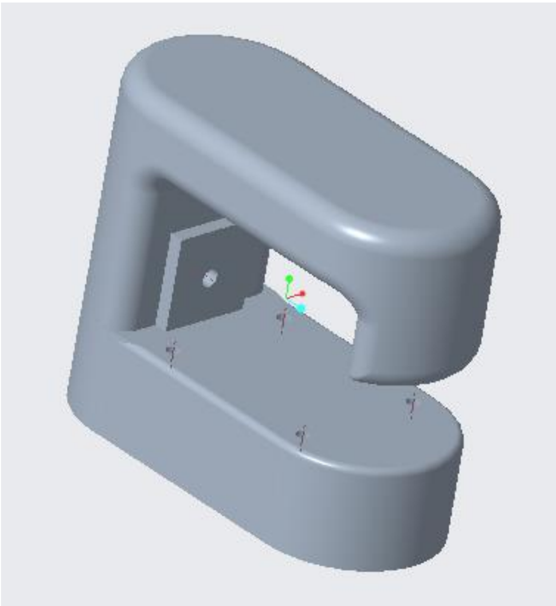


Figure 19: White Case

- Plastic structure:

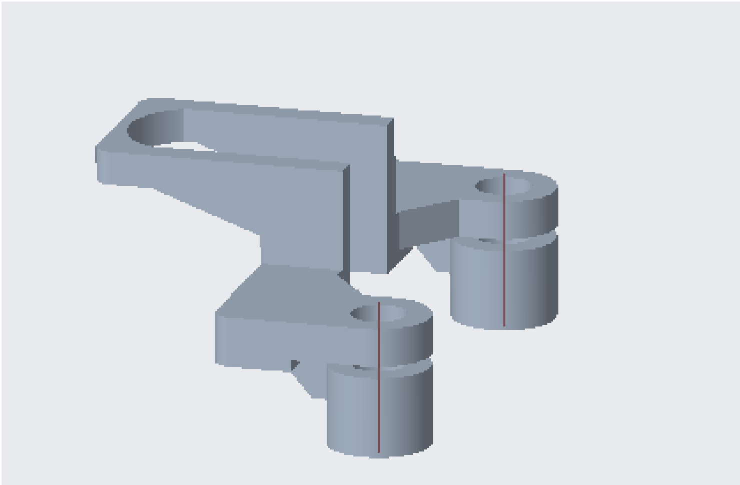


Figure 20: Plastic Structure

11. MANUFACTURING COST ANALYSIS

As Apriori was not available, we will estimate the cost of the original parts using the website McMaster. For every component we will find out the price of the material and guess the final cost of the part after manufacturing it using that material.

- Water tank: It was probably made out of some kind of acrylic, due to its hardness and transparency. A clear cube of 6*6 inches costs 5.82$. The material used for making the water tank probably had a cost of 1.1 -1.3.
- Packing Ring: It is made out of stainless steel. From McMaster, and assuming the type of steel is Multipurpose 304 Stainless Steel and taking into consideration the small dimensions it has (it is not thick at all) the price is 3.46$ for a 36 inch bar the price of the material is around 10-15 cents.
- Grey Case: As it is a hard material it is most likely to be made out of Polyvinyl chloride (PVC) which has a price of 3.39$ for a 6*6 inch sheet. The price of the part is around 1.9-2.1$.
- White Case: Less hard than the grey case, the plastic used was probably polyethylene. A 6*6 inch sheet costs 7.57$ and as the white case is the biggest part it costs around 3-4$.
- Plastic Structure: This small item was probably made out of polyethylene. Being a 6*6 inch cube worth 3.56$ the part costs around 0.4-0.5$.

12. NEW CONCEPTS

The first way of improving the recyclability of the parts is trying to make as many of the parts as possible of the same material. As a result, these components can be recycled together. As most of them were made using the manufacturing process injection molding, it will be easier to recycle if all the material is melted again so it can be used again for other molds. I believe that all five of the components analyzed previously could be made out of the same material. Perhaps the grey case has to be harder and resist higher temperatures than the rest of the parts, but the main purpose of all the parts is to either protect some internal components or hold things in place. This can be achieved by using a plastic that is not only cheap and resistant, but also one that has leaves a smaller footprint while and after being used.
The second is to reduce the number of parts. This is related to the previous bullet point. As some parts can share material between each other and as stated in the *Design for Assembly (DFA*) analysis, the water tank and the white protective case can be both part of a component that serves both purposes and separately the grey case, the packing ring and the plastic structure can be reduced into only one component.

The third is choosing the material that the parts are going to be made of. The goal is to find a material that is the can maximize the profit (reducing costs so making it cheap) while serving its purpose correctly (can resist impacts and high temperatures and has a decent hardness) and being as recyclable as possible. Taking into consideration this last goal, the two materials that are relatively cheap and are the easiest to recycle are Polyethylene Terephthalate (PET) and High-density Polyethylene (HDPE).

- Polyethylene terephthalate (PET): most common thermoplastic polymer resin. The majority of its production is for synthetic fibers, being plastic bottle production the second main use. It is the easiest plastic to recycle: The recycling process consists of first crushing the plastic into small pieces that are later reprocessed to make polyester fiber. It can be either semi-rigid or rigid and it is very lightweight. It is relatively resistant to impact and is decently strong. In addition, it has a good thermal and chemical resistance. However, it is hygroscopic. In other words, it absorbs water from its surroundings. When it is heated the water hydrolyzes the material, which reduces its resilience. As the garment steamer works with both water and high temperatures it is not the most suitable option in this case.

- High-density polyethelene (HDPE): it a thermoplastic polymer obtained form ethynele. Its main characteristic is the high strength to density ratio it has. The density can range from 930 to 970 kilograms per cubic meter. The HDPE is opaque and can stand high temperatures for short periods of time. Moreover it is resistant to solvents and has an excellent thermal and chemical resistance. It is very suitable because it is easy to manufacture using injection molding and extrusion. It has a high tenacity, very lightweight and very suitable for thermal and mechanical recycling. The recycling process consists of chopping the plastic first and then it is washed and converted into small flakes. It is more cost-effective than PET.

We will develop a Pugh Matrix to find out which material to use for the parts. A Pugh Matrix consists of a matrix where two or more different elements are compared (in this case PET vs HDPE). Rows represent each quality that is being compared. For every element and quality, a number ranging from 1 to 5 will be assigned (1 being the lowest and 5 the highest). Then all the numbers will be added up for each element and the one with the highest score is the one that will be chosen.

CHARACTERISTIC	PET	HDPE
Recyclability	5	4
Thermal Resistance	4	5
Chemical Resistance	4	4
Strength to Density	3	5
Impact Resistance	4	4
Cost-effective	3	5
Weight	3	5
Manufactured with Ease	4	5
Total	30	37

Table 13: Pugh Matrix

Comparing both materials, it is safe to say that the best option is the High-density polyethylene (37 > 30). Not only does it have a better resistance to impact but also works better at high temperatures when water is part of the functioning. Furthermore the recycling process produces great results without costing as much money as PET.

13. CAD MODELLING OF THE NEW PRODUCT

- New White Case:

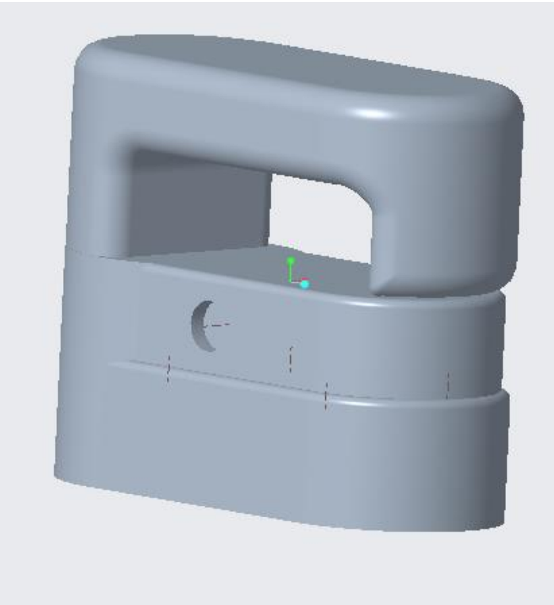


Figure 21: New White Case

- New Grey Case:

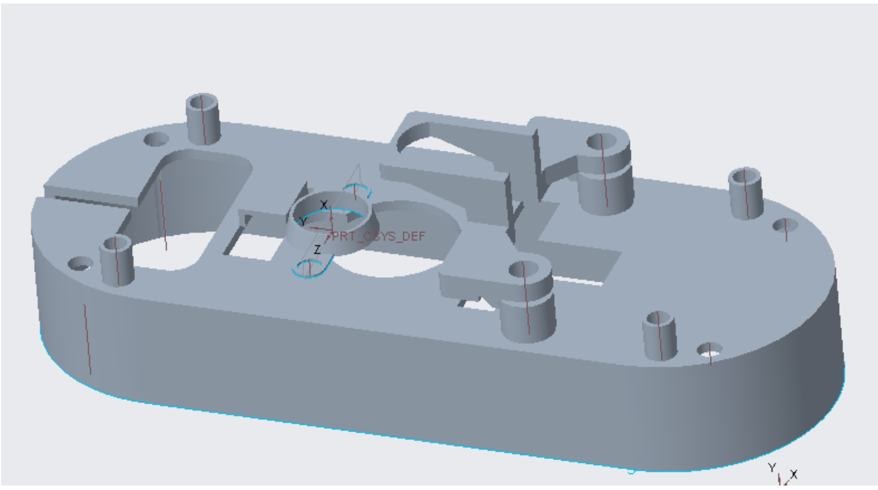


Figure 22: New Grey Case

14. DESIGN OF EXPERIMENT METHOD

The next step is to perform a rudimentary design of experiment method to test the new product with the new sub-assemblies. By choosing some variables that are related to both the old and the new prototype, we have the chance of comparing how the two products are performing when it comes to that variable.

Therefore, we first have to identify the input variables that we are going to be using throughout the experiment, and those are the number of parts, the material used and the water tank refilling time. On the other hand, the output variable will be the overall assembly time required.

1. The number of parts (X_1): one of the main purposes of this project was to reduce costs, so one of the main objectives was to get rid of all the unnecessary parts. Moreover, this variable has a direct impact on the recyclability.
2. The material used (X_2): as stated in the previous bullet point, recyclability is of utmost importance. Therefore, analysing the material used is crucial for this experiment.
3. Water tank refilling time (X_3): as the water tank was combined with the white case into a new component now it takes less time to refill, not being necessary to remove the tank from the case in order to perform this task.

For every variable previously stated, two values will be assigned. First a "low" value, which is the case with the best performance that makes the assembly time the lowest and a "high" value which represent a worst scenario for the variable. The low value will be identified by the number -1 and the high value by +1. In the low column we will have: the least amount of components as it takes less time to assemble it if it has less parts, the material HDPE as it is a bit harder than PE and easier to handle which will translate into less assembly time too and finally the time needed to refill the water tank which is not only related to the customer satisfaction but also as the water tank is attached now to the white case it lowers the assembly time.

Variable	Low (-1)	High (+1)
X_1	12	15
X_2	HDPE	PE
X_3	30	40

Table 14: Variables

The procedure used will be the one called '2^k Factorial Design'. The letter 'k' refers to the number of variables in our problem. As we are working with three variables (number of parts, material used and water tank filling time), there will be a total of 2^3=8 different combinations (as each one has a low and a high value). For each one of the combinations we will perform three different trials, in other words, three measures to make sure that the measure taken is valuable.

The design matrix will be filled with three measures for every combination of variables and the average of these three measures will be calculated. These measures are random values based on the assembly time calculated on *Section 15: Comparison*, as it would take the physical prototype of the new design and a device that measures the time it takes for every combination. The device, for instance a chronometer should be able to get at least one decimal for every measurement. The reason behind the three different trials is to prevent external factors to have an impact on the final result, for example, what happens if a part breaks during assembly. In order to avoid this, the average is going to be used.

Combination	X_1	X_2	X_3	Trial 1	Trial 2	Trial 3	Average Time
1	-1	-1	-1	139.4	139.6	138.7	139.2
2	1	-1	-1	146	146.7	148.2	146.9
3	-1	1	-1	142.1	140.9	142.3	141.7
4	-1	-1	1	140.5	140.8	139.9	140.4
5	1	1	-1	148.7	149.1	149.1	148.9
6	-1	1	1	142.5	141.6	142.2	142.1
7	1	-1	1	147.3	147.3	147.5	147.4
8	1	1	1	149.5	148.6	149.2	149.1

Table 15: Design Matrix

If you want to analyze the effect of each variable separately, there are two combinations of variables for that, which are leaving the other two variables unchanged and just modifying the value of the studied variable. For instance if X_1 was to be analyzed you can pick combinations 1 and 2, which leave variables X_2 and X_3 with the low value and just switches X_1. Bearing that in mind, the next step is to calculate how the interaction between the input variables affects the output ones. The variables used for interaction will be:

1. X_{12}: The interaction between variables 1 and 2.
2. X_{13}: The interaction between variables 1 and 3.
3. X_{23}: The interaction between variables 2 and 3.
4. X_{123}: The interaction between variables 1, 2 and 3.

In order to calculate the variable X_{12} for instance, the columns of variable 1 and 2 will be multiplied.

Combination	X_1	X_2	X_3	X_{12}	X_{13}	X_{23}	X_{123}	Average Time
1	-1	-1	-1	1	1	1	-1	139.2
2	1	-1	-1	-1	-1	1	1	146.9
3	-1	1	-1	-1	1	-1	1	141.7
4	-1	-1	1	1	-1	-1	1	140.4
5	1	1	-1	1	-1	-1	-1	148.9
6	-1	1	1	-1	-1	1	-1	142.1
7	1	-1	1	-1	1	-1	-1	147.4
8	1	1	1	1	1	1	1	149.1

Table 16: Calculation Matrix for main effects

With Table 16 already filled, we can obtain how the interactions affect the output variable. To calculate each effect value, you have to multiply the sign of the cell that corresponds to that column by the average time and sum all the results. Finally, the resulting number must be divided by half of the combinations used, which in this case is 4. For example, the equation to calculate E_1 is:

$$E_1 = \frac{[-1*139.2+1*146.9-1*141.7-1*140.4+1*148.9-1*142.1+1*147.4+1*149.1]}{4} = 7.22$$

This will be done for seven different ranks, being the three original variables and the four interactions. Moreover, using the graphical significance method we will obtain not only the probability but also the variance and standard deviation. The probability will be calculated using the following formula:

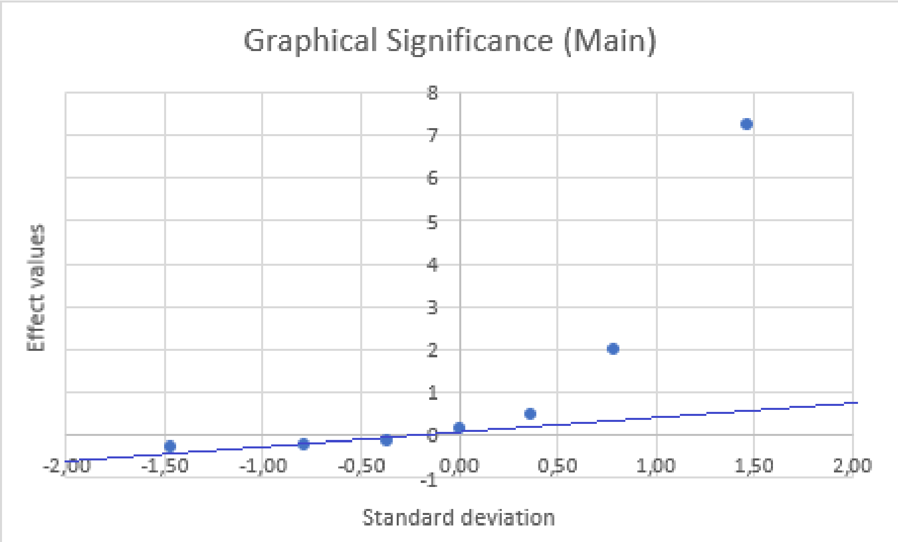
$$\text{Probability (\%)} = \frac{100*(i-0.5)}{2^n - x}$$

Being i the rank of the effect, n the number of trials (3 in this case) and x is 1.

Rank	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Effect Value	7.22	1.98	0.57	-0.13	-0.22	-0.28	-0.27
Probability (%)	92.86	78.57	64.29	50	35.71	21.43	7.14
Standard Deviation	1.47	0.79	0.37	0	-0.37	-0.79	-1.47
Effect	E_1	E_2	E_3	E_{12}	E_{13}	E_{23}	E_{123}

Table 17: Ranked effects and their corresponding probabilities

The standard deviation has been calculated using the NORM.INV(%_value_decimal, mean(=0), standard_deviation(=1)) in Excel. To see how each variable affects the assembly time, we will plot the effect value over the standard deviation.



Graph 1: Graphical significance

After plotting the effect values over the standard deviation, we can conclude several things. First of all, we can observe that the values E_1 and E_2 have a huge impact on the assembly time as they clearly not close to the straight line (both of them are above it). On the contrary, the time required to fill the water tank is not relevant to the time needed to assemble the garment steamer (E_3 is slightly over the line but is not significant enough). Moreover, the interactions between the variables do not affect the assembly time, as expected. These results prove what we calculated on the assembly time section in Section 15: Comparison, as we reduced the number of components and changed the material and the assembly time was reduced (from 153 to 139 seconds).

15. COMPARISON

After redesigning the garment steamer, it is time to make a comparison with the original product, to see if there was a real improvement. We will compare not only cost and assembly time, but also recyclability and environmental impact.

○ ***15.1 COST:***

We will call white case to the new part that contains the original white case and the water tank and grey case the part that was made of the original grey case, the plastic structure and the packing ring.

Knowing that the new material is high-density polyethylene, the price according to McMaster is of 7.57$ for a 6*6 inch sheet of moisture-resistant HDPE. We want it to be moisture resistant as the garment steamer works with water in both liquid and gas form. For the white case the material cost will be between 4$ and 5$. The grey case as it has smaller dimensions will cost between 2.5$ and 2.8$.

Now we should add the manufacturing cost of each part. The method used for both cases is going to be injection molding.

- White Case: in order to calculate the cost per unit we will assume the following:

  - ✓ Part volume: 83.3 in^3
  - ✓ Quantity: 20000 units
  - ✓ Material: HDPE
  - ✓ Density= 0.0345lb/in^3
  - ✓ Material price= 0.85 $/lb)
  - ✓ Cycle time=60 seconds
  - ✓ Machine rate: 10$/hr
  - ✓ Setup labor: 10$/hr
  - ✓ Direct labor: 10$/hr
  - ✓ Machine set-up time: 0.2 hrs
  - ✓ Mold cost: 3000$

The result is:

Cost Summary

1. Injection Molding	$87,854 ($4.393 per part)
Material cost	$78,180 ($3.909 per part)
Production cost	$6,674 ($0.334 per part)
Tooling cost	$3,000 ($0.150 per part)
Total cost	**$87,854**

Table 18: Cost summary of white case

As we can see each parts cost 3.91$ of material (almost the same as what we obtained from McMaster) and the production cost is of 0.334$ per unit. The mold cost is 0.15$ per unit.

- Grey Case: the assumptions are the same, the only aspects that change are the part volume and the cost of the mold
    - ✓ Part volume= 32.04 in^3
    - ✓ Mold cost= 2000$

Cost Summary

1. Injection Molding	$56,790 ($2.840 per part)
Material cost	$48,116 ($2.406 per part)
Production cost	$6,674 ($0.334 per part)
Tooling cost	$2,000 ($0.100 per part)
Total cost	**$56,790**

Table 19: Cost summary of grey case

Each grey case costs around 0.334$ to produce using injection molding and 0.1$ per part to make the mold.

Assuming the original white case and water tank had the same production cost than the final white case (in injection molding most of the cost is the mold the cost of making each part does not vary that much).

The cost of the original parts was:

White case + Water tank: 1.2$ (water tank material) + 0.334 (production cost of water tank) + 0.15$ (water tank mold) + 3.5$ (white case material cost) + 0.334 (white case production cost) + 0.15$ (white case mold) = ***5.668$.***

Grey case + Plastic structure + Packing Ring: 0.15$ (packing ring material cost) + 0.45$ (plastic structure material cost) + 2$ (grey case material cost) + 0.334 (production cost of grey case) = ***2.934$.***

Note that we disregarded the production cost of the packing ring and the plastic structure as they are very low but increasing a bit the cost of the grey case to ***3$*** can make it closer to reality.

	Grey Case	White Case	Total
Original Cost ($)	3	5.668	8.688
New Cost ($)	2.84	4.393	7.233

Table 20: Cost comparison

As we can see both parts have their costs reduced (2.84<3$ and 4.393<5.668$). But not only have the costs decreased, but also other factors such as environmental impact or assembly times have been improved. As the number of parts has been reduced it will take less time for the worker to assemble the parts.

The market of the garment steamer was 39.99$ (*Section 2: Market data and competitors*), the manufacturing cost is around 23.994$ (60% of market price) as calculated in *Section 3: Manufacturing Cost*. Assuming that the cost of the other parts remains the same, the cost of the original steamer without the combined parts is:

Cost 1= 23.994 - (3 + 5.668) = 15.326$

Adding the cost of the new parts:

Cost 2 = 15.326 + 2.84 + 4.393 = 22.559$

If 20000 units were produced, the manufacturing cost of all of them was originally:

Original Total Manufacturing Cost = 20000 * 23.994 = 479880$ per year

Dividing by the manufacturing cost of the new product (22.559$):

New number of units = 479880 / 22.559 = 21272.22

In other words, 1272 more garment steamers can be manufactured each year without varying the total manufacturing cost. If reducing costs was the goal in this case, the procedure would be:

New Manufacturing Cost = 451180 $

- If the company wanted to still produce 20000 units a year, the cost would decrease to 451180$, which is 28700$ less than before.

- ***15.2 ASSEMBLY TIME:***

We will calculate the approximate assembly time of both the original garment steamer and the redesigned one.

- Original:

Part Number	Number of Items	Time (s)	Total Time (s)
1	4	6	24
2	1	1.5	1.5
3	1	1.5	1.5
4	1	5	5
5	1	3	3
6	1	3	3
7	1	8	8
8	2	1.5	1.5
9	1	5.5	5.5
10	1	5	5
11	4	1.5	6
12	2	1	2
13	13	6	78
14	1	5	5
15	1	4	4
Total			153

Table 18: Assembly time of original product

It takes more or less 153 seconds to assemble the fifteen parts of the original the garment steamer. The next step is to repeat the procedure for the redesigned steamer and compare both times.

- Redesigned:

Part Number	Number of Items	Time (s)	Total Time (s)
1	4	6	24
2	1	1.5	1.5
3 +9+10	1	2	2
4+14	1	6	6
5	1	3	3
6	1	3	3
7	1	8	8
8	2	1.5	1.5
11	4	1.5	6
12	2	1	2
13	13	6	78
15	1	4	4
Total			139

Table 19: Assembly time of redesigned product

Note that Table 19 has fewer rows, are parts 3, 9 and 10 have been combined into one and 4 and 14 have too. As a result, the time required to assemble the steamer has decreased from 153 seconds to 139 seconds just by combining several parts together. In the previous section we stated that the approximate number of items sold was 20000. If each part requires 153 seconds to assemble and the redesigned one takes only 139 seconds the amount of units that can be assemble now is:

$$\text{QUANTITY} = \frac{20000*153}{139} = 22014.39$$

This means that 2014 more steamers can be assembled over a year using the same amount of worked time.

15.3 Environmental Impact and Recyclability:

In order to understand the impact the new garment has we first have to understand what the circular economy is. A circular economy is a kind of economy that consists of loops in which materials, products and components are part of an implemented system in which sustainability and environmental harm are a priority. This system of resource utilization is based on three major processes, reusing, recycling and reduce, the three R's.

- Reusing: the act of extending the life of a product and continue taken advantage of its properties in your favor. This can either be reusing the product again with the same purpose it serve in the first place or finding a way of using it in another way that can satisfy other needs.
- Recycling: transforming a product into a raw material so another product can be made using the material of the original discarded one. Most of the materials on our planet can be recycled. Depending on the material that wants to be recycled this can be an expensive process.
- Reducing: in the waste hierarchy, reducing means consuming what is essential and at the bottom of this hierarchy, as if there is less material used there is less material that has to be reused or recycled. To reduce the amount of products we use we have o find others that can serve the same purpose, or by finding multi-use items. Moreover, already existing products should be used optimally and not be discarded when they start failing.

While closed cycles are of upmost importance for circular economy, as all materials and processes produce less waste and less impact on the environment if they start over again, renewable energy also plays an important role. Although energy cannot be reused or recycled, the circular economy is fed by renewable energy, as it has a smaller environmental footprint.

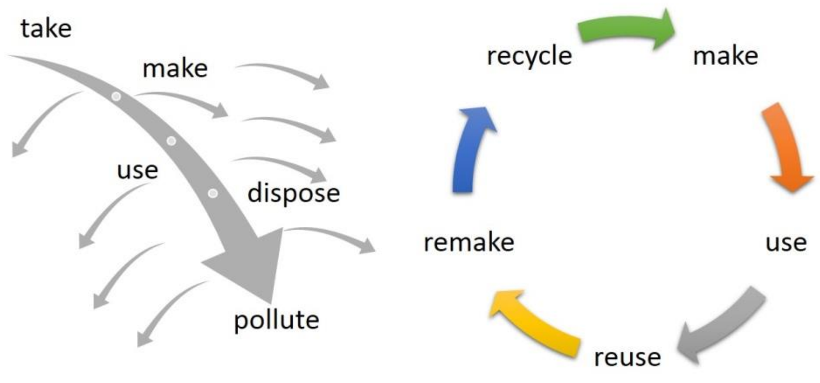


Figure 23: Traditional economy versus circular economy

Without doubt the best way of ending up being sustainable and trying to cut down on the amount of waste produced is raise awareness among the society. Implementing laws that penalize those who do not follow some rules when it comes to reducing, recycling and reusing can be somehow beneficial as people may do it just to not get fined or punished. However, I believe the optimal strategy is to let people know how bad the situation is and how much we need their cooperation in this situation. This can be done with the help of media, politicians and experts on the subject like scientist.

However, it is true that many citizens want to contribute to this cause but do not find a successful way of doing it and every day that passes people are more and more aware of the current situation. Recent studies showed that the main problem when it comes to recycling is the lack of space that people have in their home for the high amount of bags that are full of waste that wants to be recycled. This makes it hard for them to separate the waste as much as separating waste means different bags for each product, which increases the number of bags in every home. One solution would be having more recycling points per capita and with a larger variety of containers, so that people can separate items easily.

In addition, improving the labeling in products can make a huge difference. Sometimes it is unclear whether a certain product should be discarded as a certain material or not. As citizens do not have sometimes the required knowledge to identify which dumpster an item goes to, the government should enforce strict rules for companies so they improve the labels on their products. This is because even if companies make an effort to make it easier for us, it is still up to us and if there is no punishment for harming the planet there is a part of the society that will continue not recycling. Therefore, design for recycling is a tool that really helps to make our lives uncomplicated but has a limited impact. On the contrary, laws seem to work more effectively.

These are important ways that the citizens have to do in order to take care of our world. However, businesses can also help. When it comes to the new garment steamer, it introduces new features that facilitate the recycling of the product and lower the impact that it has on the environment.

- ✓ The first is reducing the number of different materials used in parts, make specifications for every product indicating which materials are recyclable and which not and redesign these products so that they have less components. In this case there are fewer parts (12 instead of 15). Therefore, and as stated previously, the assembly time is reduced which means that it takes less effort for the customer to disassemble the product and separate its component for recycling. Moreover there are less different materials to discard. Not only does this make it easier for the customer to separate, but it also means that fewer labels are necessary and less indications from the company indicating how to recycle each component.

- ✓ The material of the parts that were combined was changed to HDPE. As we have previously stated, HDPE is one of the plastics that is easiest to recycle. It is a type 2 plastic, which is considered to be Eco-friendly, which means that they are mainly made from post-consumer products and at the end of their life can be recycled. It does not give harmful fumes into the environment as it is the most environmentally stable plastic. Once it is recycled there is barely any necessary maintenance and has extremely good resistance to external agents such as oil, salt spray or insects. It also does not contain harmful allergens, heavy metals or phthalates.

ESE World B.V carried out a test and demonstrated that HDPE can be recycled up to 10 times. Injection molding, which is the main manufacturing method used for the parts, does not change the material properties during the time they are being used. If the garment steamer is used for 5 or 10 years, then the total life span of the materials can be of around 50-100 years. HDPE is also the material used in 97% of bottles in America, meaning that these parts can be easily discarded with products of our daily life and that everyone has at home.

16. SUSTAINABLE DEVELOPMENT GOALS

The sustainable development goals (SDG) are a collection of 17 global goals designed to be “blueprint to achieve a better and sustainable goal”. All of them are connected between them and are expected to be achieved by 2030 and they address problems related to poverty, inequality, climate change, environmental degradation, peace and justice. They promote prosperity while protecting the world. The 17 goals are:

1. No poverty.
2. Zero hunger.
3. Good health and well-being.
4. Quality education.
5. Gender equality.
6. Clean water and sanitation.
7. Affordable and clean energy.
8. Decent work and economic growth.
9. Industry, work and infrastructure.
10. Reduced inequalities.
11. Sustainable cities and communities.
12. Responsible consumption and production.
13. Climate action.
14. Life below water.
15. Life on land.
16. Peace, justice and strong institutions.
17. Partnership for the goals.

After reading the seventeen different Sustainable Development Goals (SDG) designed by United Nations to achieve a more sustainable future, I found some of them that are involved in my senior design project: “Re-design for manufacturability of a garment steamer”. Not all the goals are equally relevant to this thesis. There is one primary objective which was taken into account and that was expected to be achieved by developing the project throughout all its sections. In addition to this, there are several goals that are also involved in it but with a secondary role. In other words, the main purpose of the redesign of the steamer was not to meet those goals, but it does partially.

✓ The primary SGD is number 13: “Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy”. Since preindustrial times the average temperature has increased over 1ºC due to the emissions of greenhouse gases such as CO_2 (carbon dioxide). In order to mitigate devastating consequences the United Nations has established in the *Paris Agreement* a maximum increase of 2 ºC. Furthermore, the CO_2 concentrations are at their highest levels in over 800000 years. Although these emissions have several sources, from 1850 it is known that most of them are due to the human being (mainly aerosols). Therefore urgent solutions have to be achieved. The analysis and redesign of the garment steamer plays a very important role in climate change and reducing emissions. One of the main goals of the project is to perform several changes to the steamer so that it either increases its recyclability or it facilitates the process of discarding the parts. This can be achieved in several ways. One might be changing the material used in some components for another that leaves a smaller environmental footprint. Another could be reducing the number of parts that the garment steamer has, so the disassembly is easier and there are less different components that have to be recycled or thrown away. By reducing the number of parts we not only achieve this, but also reduce the emissions and costs during the manufacturing process, as fewer components have to be made and less material is used. Therefore, the specific goal that this TFG has is to redesign at least one component or subassembly of the garment steamer and to select an optimal material in order to reduce its impact on climate change and reduce as much as possible the emissions.

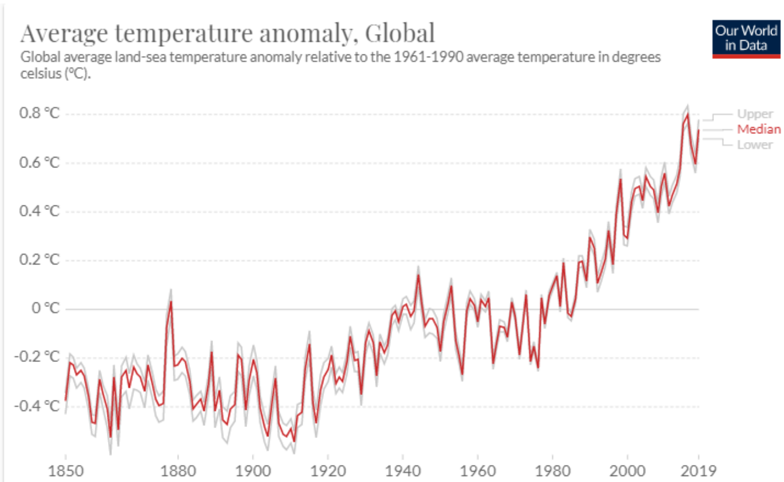


Figure 24: Average temperature anomaly

✓ Moreover, one secondary SDG that is also affected by my TFG is number 12: “Ensure sustainable consumption and production patterns”. Since the Industrial Revolution, businesses have begun to produce in massive quantities. The main objective was to reduce costs as much as possible, in order to maximize the benefits obtained. The issue is that in order to achieve it they disregarded the environmental impact that their products would have while being manufactured. As stated previously, one of the main objectives is to reduce the number of parts of the garment steamer, and to keep the minimum amount of necessary ones. This has a direct impact on the production process throughout most of the stages. First of all, it clearly reduces the amount of waste that is being thrown out, and the waste that is still being discarded can be recycled as the material makes the task easier. Secondly, reducing the number of parts means that there are fewer parts to be produced. In other words, the manufacturing process is going to have fewer steps and as a consequence is going to cut down on its emissions. Moreover, the material footprint is being drastically reduced as material that is easy to recycle will be chosen.

- ✓ Another SDG identified is number 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation". In 2000 only 1.52 per cent of the global GDP was invested into research and development. In 2016 the percentage increased to 1.68, with Europe and North America averaging 2.21 per cent. This TFG tries to make the manufacturing process more sustainable. Furthermore, as the whole aim of this project was to analyze and redesign the garment steamer in order to improve several aspects using design for manufacturability techniques, innovation was of utmost importance throughout the process. Coming up with new ideas when it comes to materials or combining parts was necessary. With this in mind the goal was to encourage innovation and increase the awareness about scientific research for countries that are less developed, as well as promoting the industrial sector.

SDG DIMENSION	SDG IDENTIFIED	ROLE	GOAL
BIOSPHERE	SDG 13: ”Take urgent action to combat climate change and its effects”	PRIMARY	Reduce emissions and the overall carbon footprint of the company ABOX by redesigning the garment so it is easier to recycle or discard.
ECONOMY	SDG 12: “Ensure sustainable consumption and production patterns”	SECONDARY	Reduce the amount of waste produced during the manufacturing process and consume effectively natural and recycled resources.
ECONOMY	SDG 9: “Develop resilient infrastructure, promote inclusive and sustainable industrialisation, and encourage innovation”	SECONDARY	Promote innovation in all countries but particularly in developing countries and increase the number of workers in the industrial sector.

Table 20: SDG summary

APPENDIX A

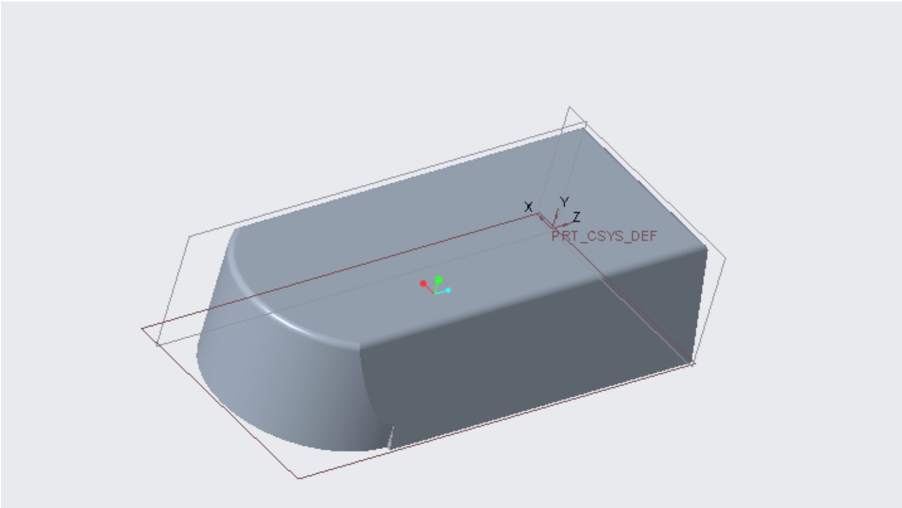


Figure A.1: Water Tank

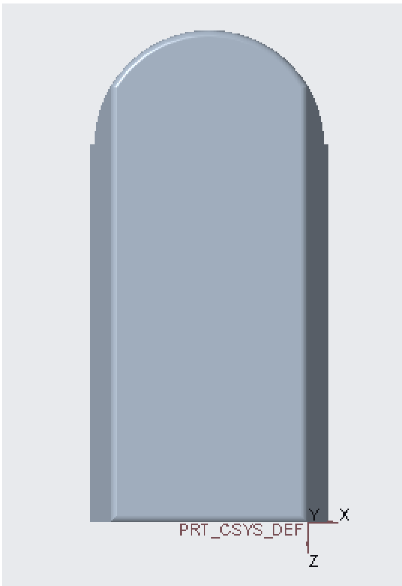


Figure A.2: Top View of Water Tank

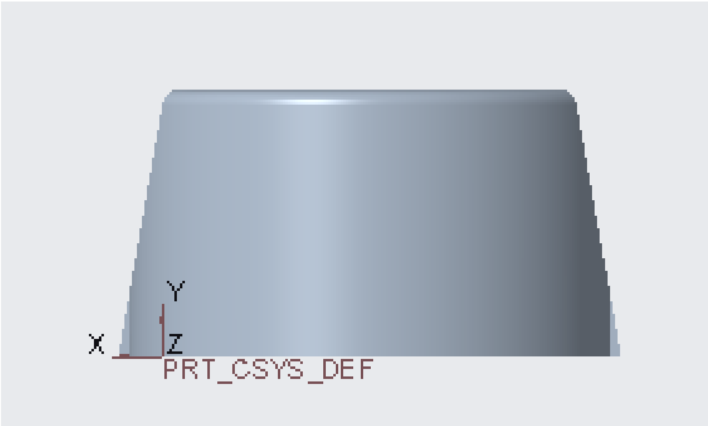


Figure A.3: Front View of Water Tank

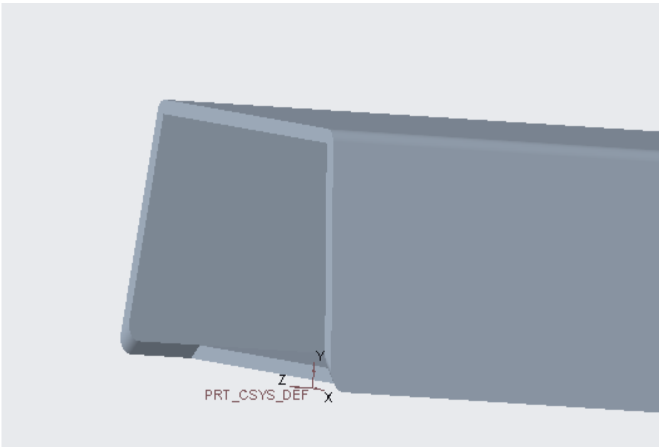


Figure A.4: Detailed View of Water Tank

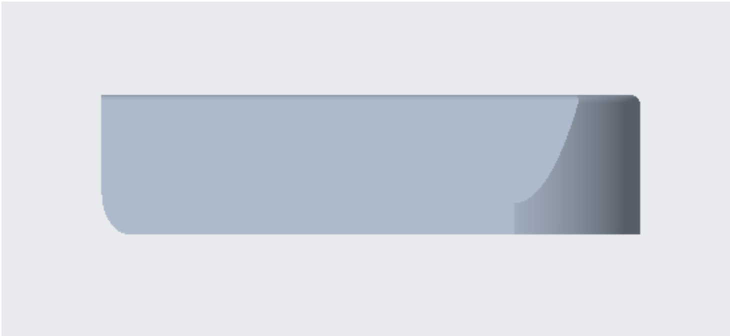


Figure A.5: Side View of Water Tank

APPENDIX B

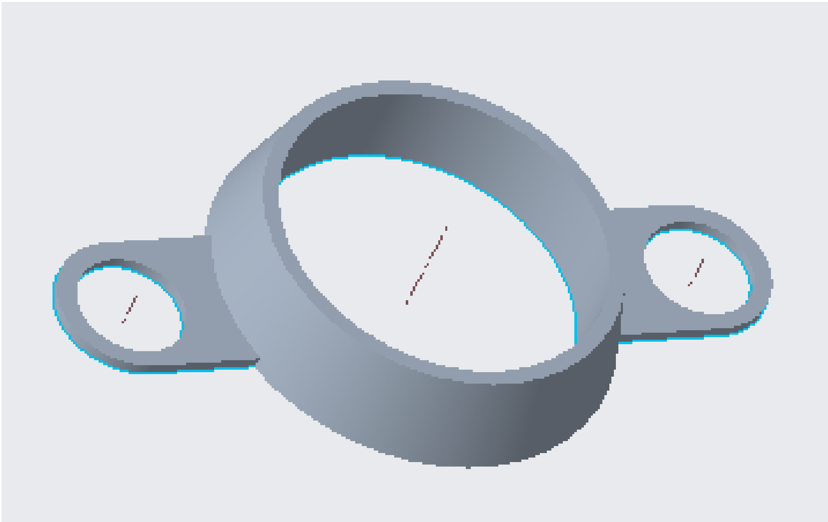


Figure B.1: Packing Ring

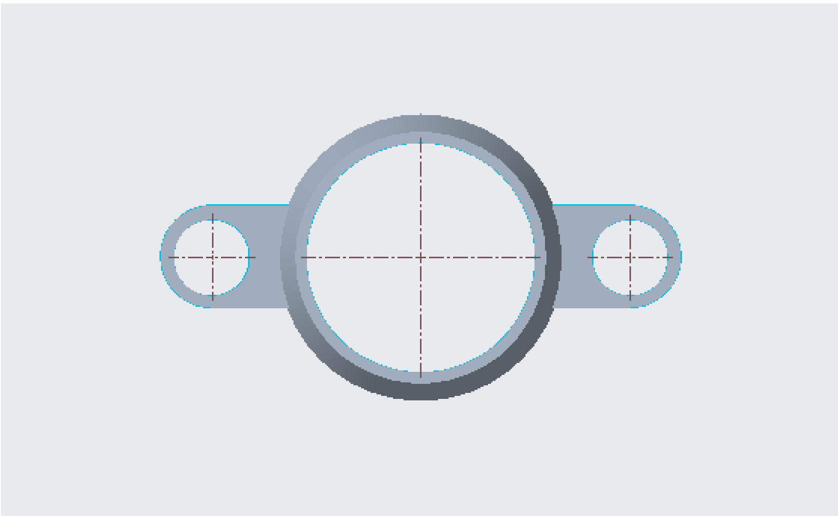


Figure B.2: Front View of Packing Ring

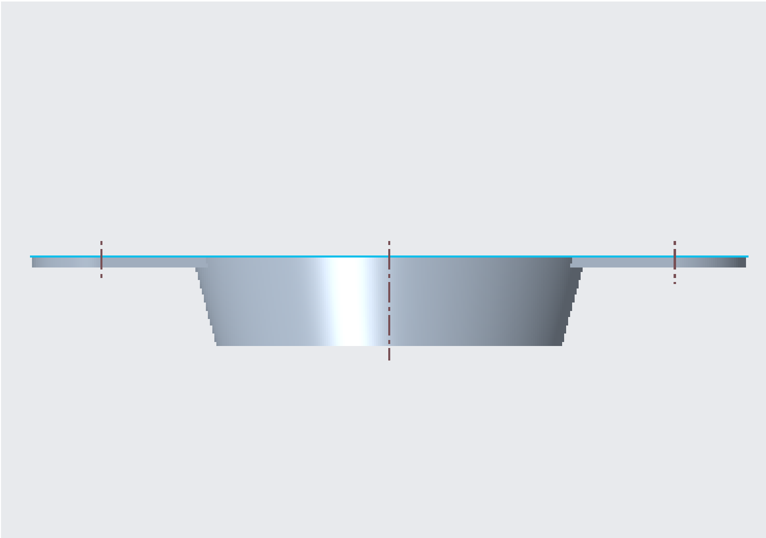


Figure B.3: Top View of packing Ring

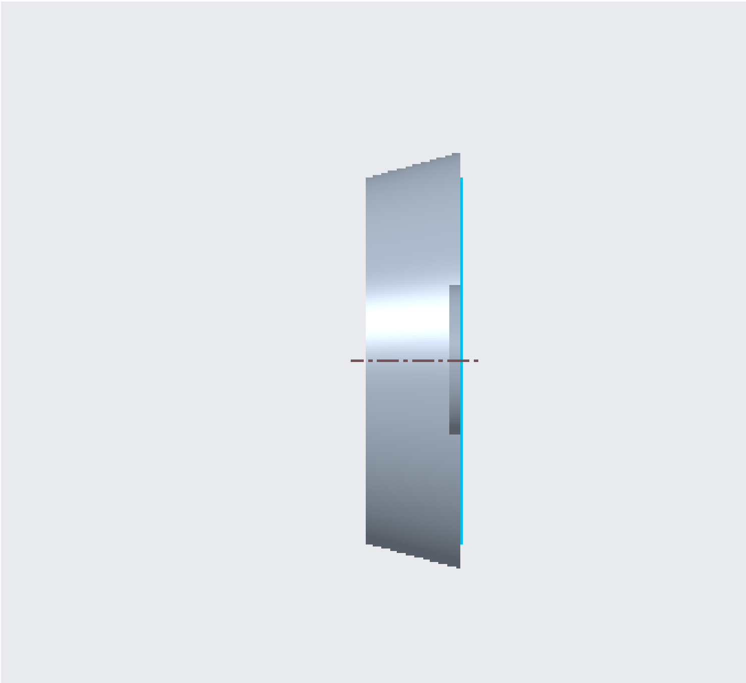


Figure B.4: Side View of Water Tank

APPENDIX C

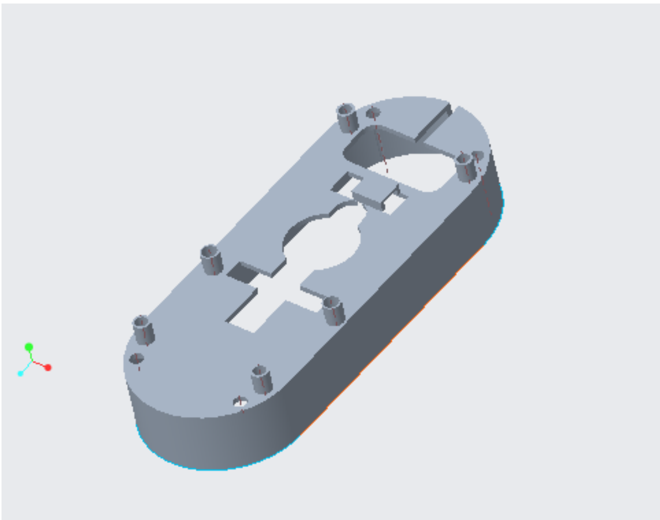


Figure C.1: Grey Case

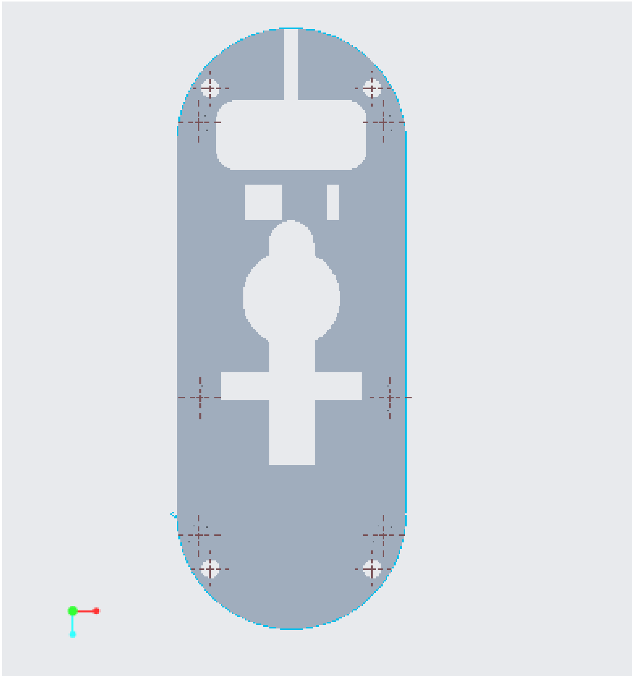


Figure C.2: Top View of Grey Case

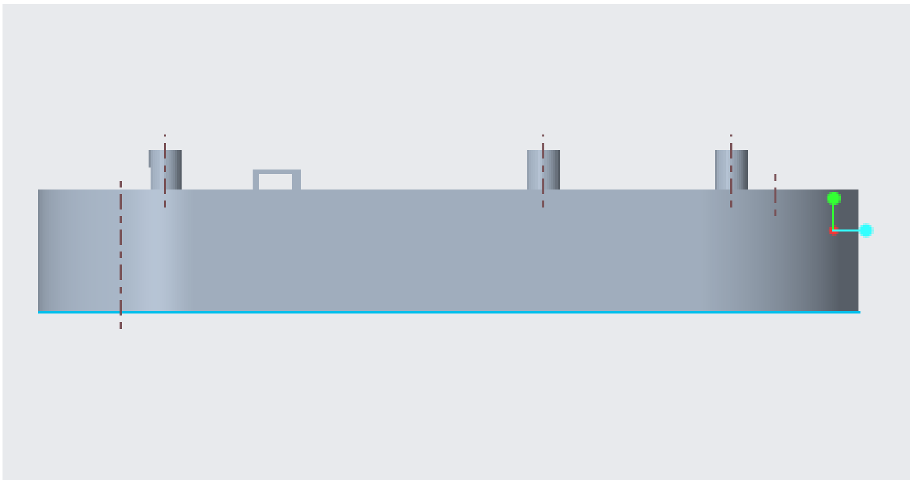


Figure C.3: Side View of Grey Case

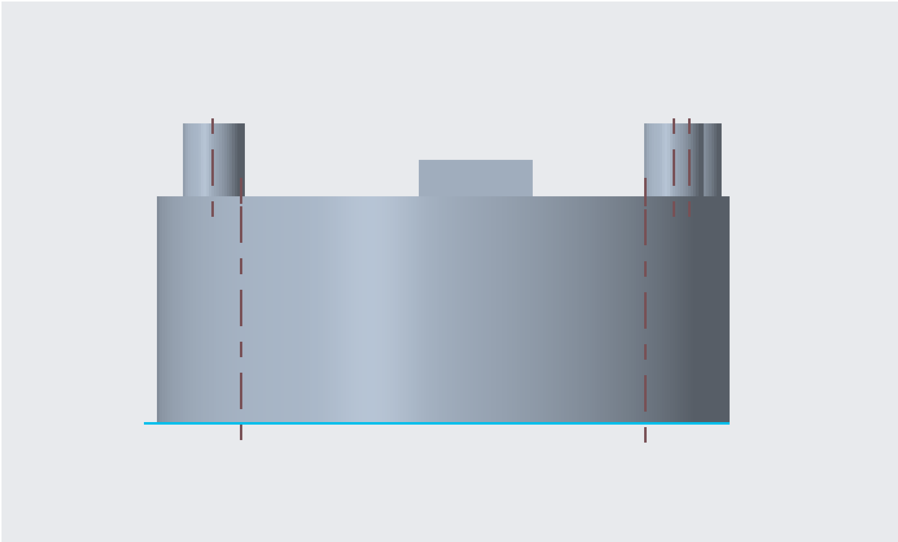


Figure C.4: Front View of Grey Case

APPENDIX D

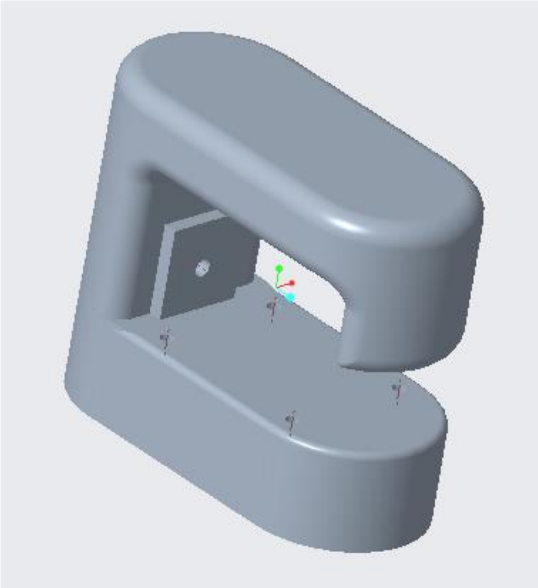


Figure D.1: White Case

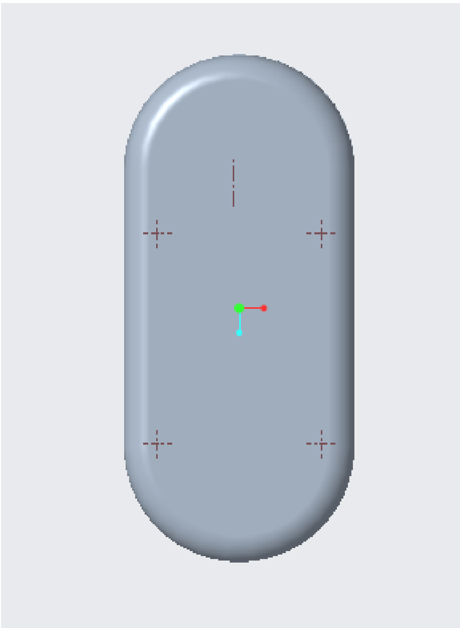


Figure D.2: Top View of White Case

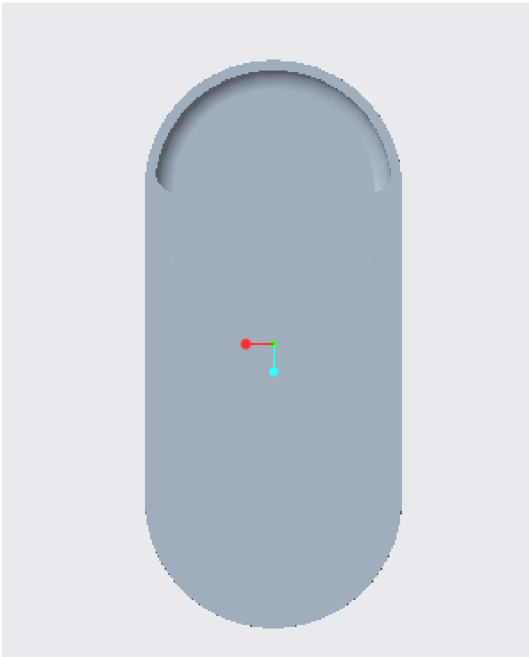


Figure D.3: Bottom View of White Case

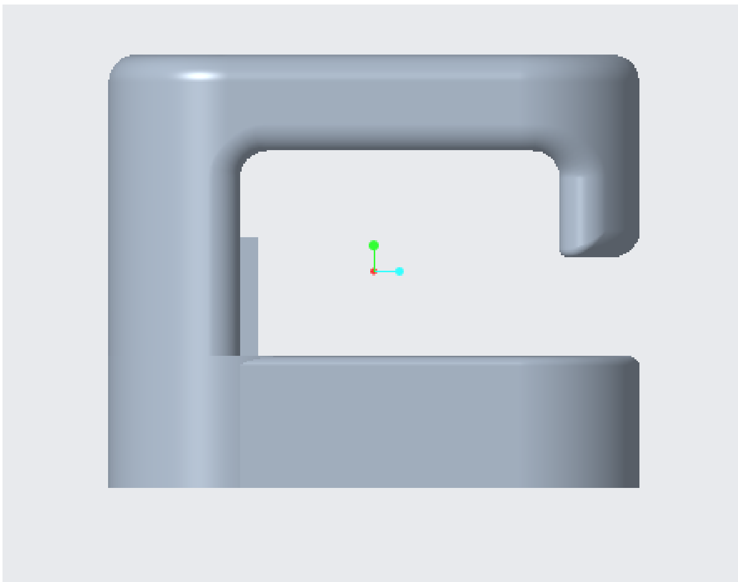


Figure D.4: Side View of White Case

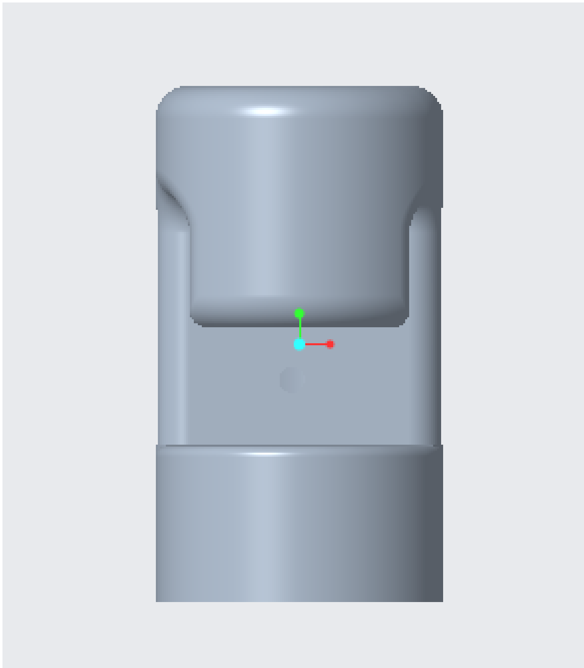


Figure D.5: Front View of White Case

APPENDIX E

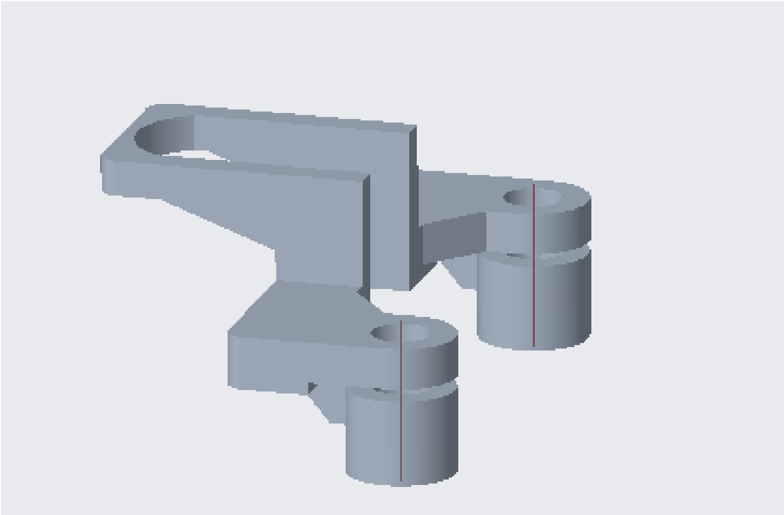


Figure E.1: Plastic Structure

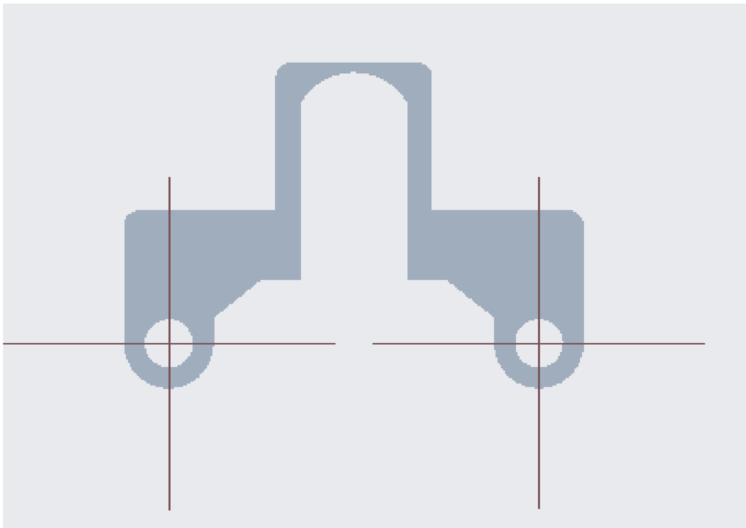


Figure E.2: Top View of Plastic Structure

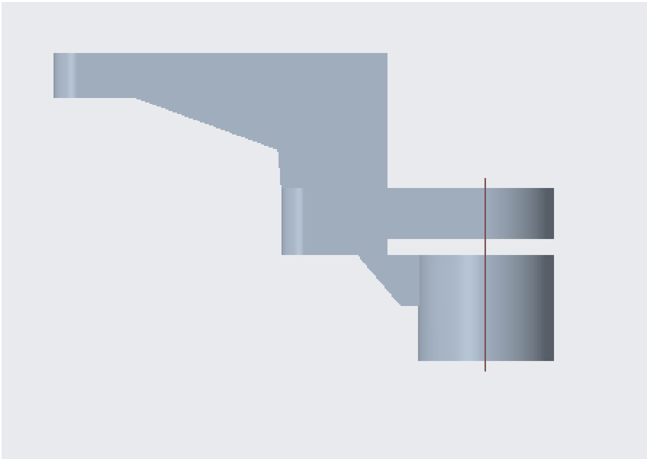


Figure E.3: Side View of plastic Structure

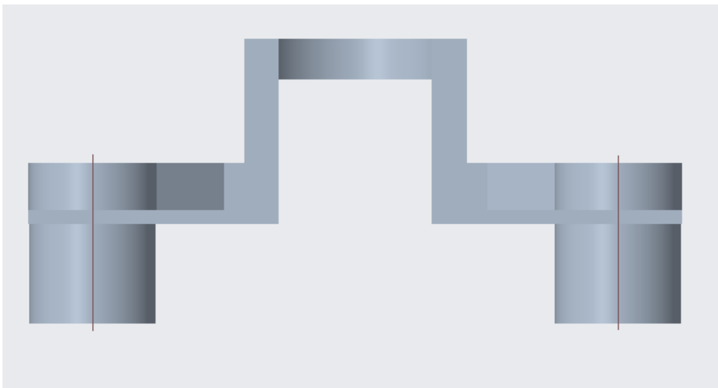


Figure E.4: Front View of Plastic Structure

APPENDIX F

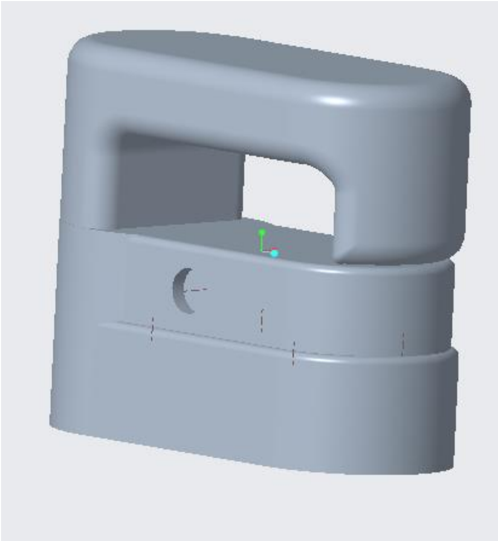


Figure F.1: New White Case

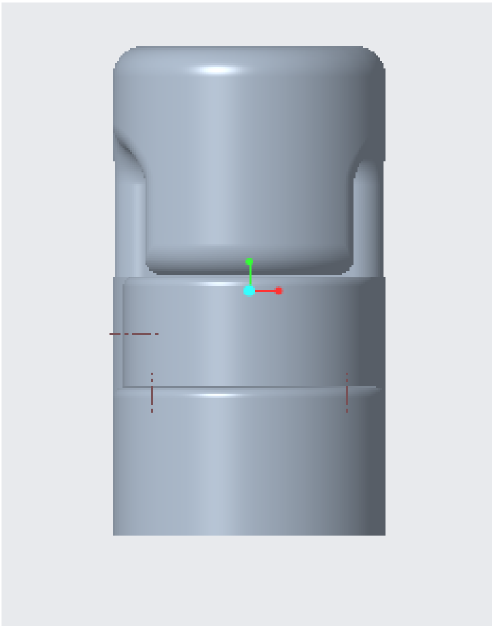


Figure F.2: Front View of New White Case

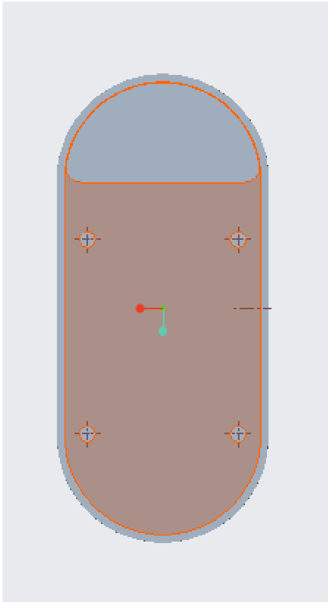


Figure F.3: Bottom View of New White Case

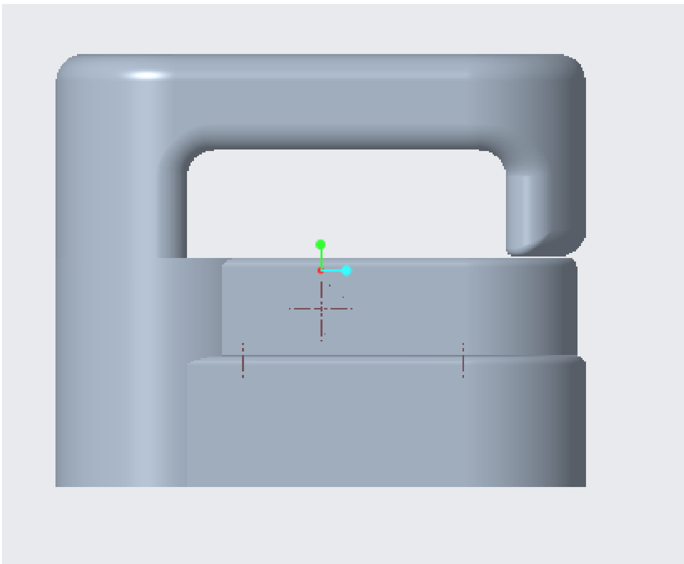


Figure F.4: Side View of New White Case

APPENDIX G

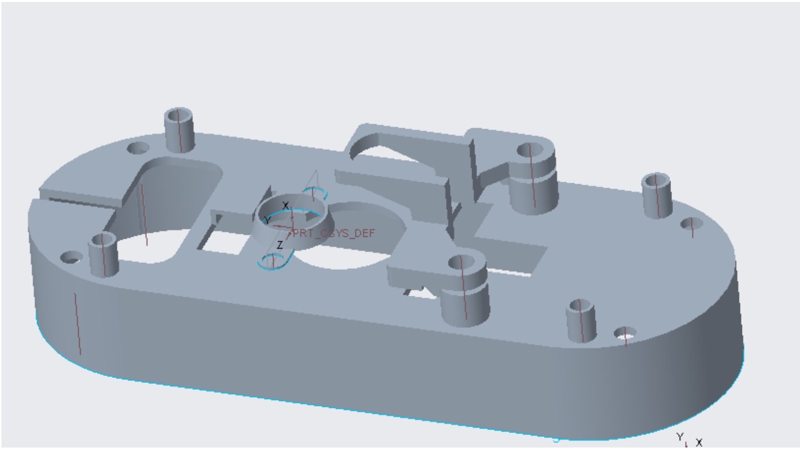


Figure G.1: New Grey Case

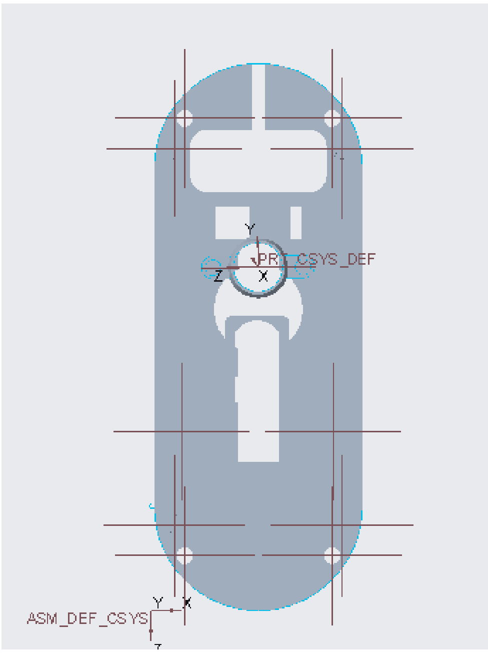


Figure G.2: Top View of New Grey Case

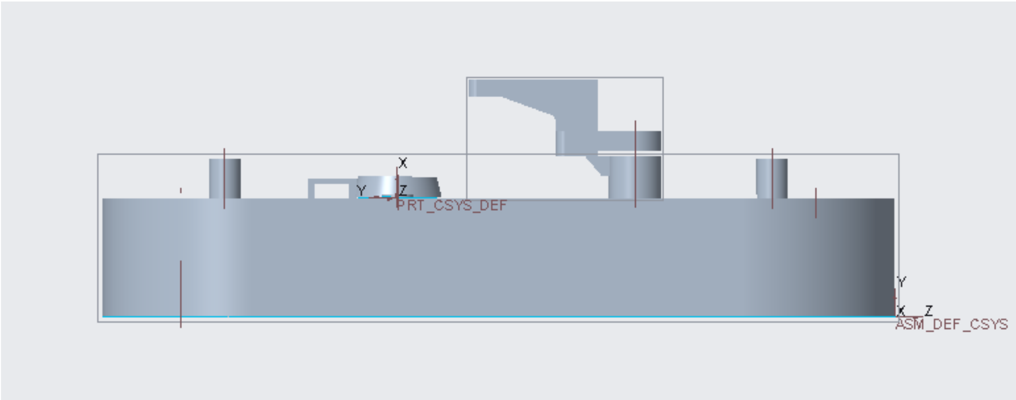


Figure G.3: Side View of New Grey Case

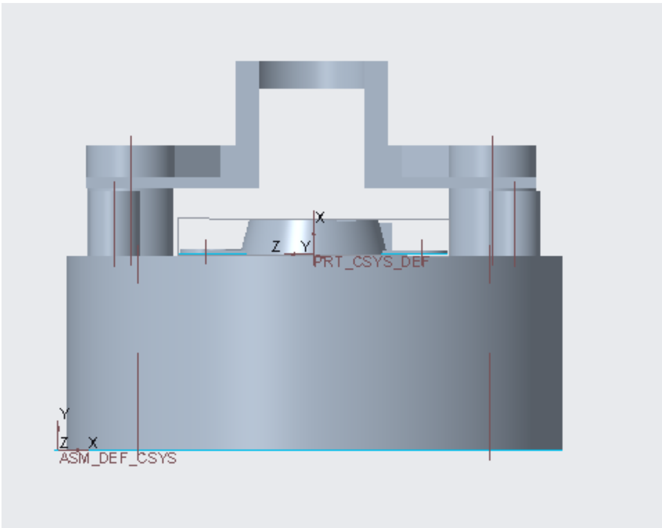


Figure G.4: Front View of New Grey Case

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