Implementing New Drying Technology at Pacific Can Beijing

A Major Qualifying Project Report

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Abstract

The goal of this project is to assist the Beijing manufacturing facility of Pacific Can to implement a new step in their aluminum can drying process using infrared lighting to reduce costs, be more energy efficient, and be more environmentally friendly. We analyzed their current drying process, created SolidWorks design models for our new proposed system, built a prototype, and tested our prototype to determine if our proposed solution works and if it can be implemented in Pacific Can's manufacturing line.

Acknowledgements

We would like to thank everyone who was able to help make this project possible and help us along the way throughout this process.

Firstly we would like to thank Beijing University of Technology (BUCT) for their hospitality and our BUCT partners for all their help in getting us adjusted and their contribution to this project.

We would also like to thank our sponsor, Pacific Can, for making this project possible and allowing us to visit often to analyses the current process and answering all the questions we had. We are very grateful for the opportunity to use their machine shop to build our prototype and learning so much from the engineers.

Lastly we would like to thank our advisors, Professor Jianyu Liang and Professor Amy Zeng for their guidance throughout this project.

Our Sponsor

Pacific Can is a leading two-piece aluminum beverage can manufacturer in China. Inaugurated in 1991, they provide flexible solutions for packaging of beverages, from beer, soft drinks, juice to teas. Pacific Can has six operational production facilities located in Beijing, Zhangzhou, Shenyang, Wuhan, Qingdao, and Zhaoqing. Their overarching mission is to “be the premier and preferred supplier to the Chinese beverage industry. Throughout the past 20 years, we have adhered to the core values which have provided us with a guiding business philosophy that helps us to prosper and grow.” (Pacific Can, 2016). These core values include serving their customer, commitment to quality, product variety and innovation, the environment, and team spirit.

Pacific Can produces various models of cans ranging from standard cans (250mL, 330mL, 355mL), large volume cans (500mL), and two-piece Slick 2oo cans (180mL, 250mL, 270mL) depending on their inquiry. Pacific Can was the first two-piece can supplier to use 8-color printing technology in the market of China making them one of the leading innovative can suppliers. They have received several awards including:

- Bronze winner of the Cans of the Year Awards (2012)
- Can of the Year and Excellence in Metal Packaging (2010)
- Two-Piece Beverage Can in ChinaCan 2010 Conference for Slick 2oo (2010)
- High-tech Enterprise Certificate (2010)
- Gold winner of The Cans of the Year Awards (2009)
- Can of the Year and Excellence in Metal Packaging in 2008 Conference for 330ml Wong Lo Kat Herbal Tea Can (2008)
- Bronze winner of The Cans of the Year Awards (2001)

Executive Summary

Pacific Can is China's leading two-piece aluminum can manufacturer. They are looking to add an innovative process to improve their current drying process that will be cost efficient, environmentally friendly, and energy efficient.

Pacific Can's current drying process entails a few steps. As the cans get out of the washing station, air is blown on the tops to get rid of excess water. The cans are then lifted from an air vacuum to be taken to the drying conveyer belt. This belt is 7.8 meters long and leads the cans through a series of ovens where hot air is blown on cans in order to dry. This oven system uses a huge amount of energy and power which is costly to Pacific Can and bad for the environment. Our team's goal for this project is creating an innovative process in Pacific Can's drying process of aluminum cans using infrared lighting to later be implemented on their current manufacturing line. This system must be energy efficient, environmentally friendly and reduce cost in order to be feasible.

Our team looked into the past group's recommendations first. They recommended to use different types of cans to see if there is a difference in drying percentage between them and to look into using waterproof infrared tubes. We did test 330mL and 500mL cans to see if there is a difference or not, but did not purchase waterproof infrared tubes due to budget. Also, we looked into the tests done by the previous MQP group. They tested 25 cans over two IR tubes which left one row not being exposed in IR lights and having a low drying percentage. We will ensure all cans receive the same amount of lighting. The prototype developed by last year's team was also not insulated well, so as we move forward we will add a layer of insulation into our prototype.

In the previous MQP's experiments, the infrared drying tubes were set at zero degrees. While this approach did dry aluminium cans in a static experiment, our team believes this approach with present other challenges in a dynamic experiment. The primary challenge is the wavelengths generated from the quartz tube may not be strong enough to reach the aluminium cans. To rectify this issue, our team plans to test the infrared drying tubes at various angles facing each other to find the most drying efficient angle. In order to be able to place the tubes in different angles, a mounting system was needed to be built for the tubes. We conducted two iteration and decide the final iteration by comparing the two designs. The final design, shown in Figure 1, uses the least material and is able to adjust angles of the IR tubes and its size. Also, a 3D SolidWorks model of our prototype was also designed in order to better visualize the conveyor belt system needed to be built. Throughout the project, a total of 3 designs of the conveyor belt system was created. The final design is shown in Figure 2. The prototype uses four rollers to drive the conveyer belt, square stocks for main structure, mesh net for supporting of the cans and belt, also an aluminium sheet for insulation system. We picked this design because it uses the least material and is very easy to build in a machine shop.

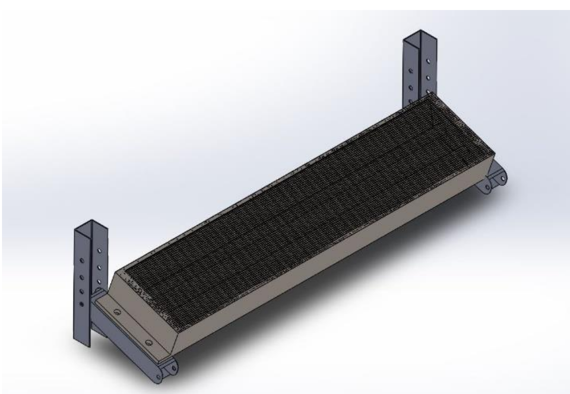

Figure 1: Final Design of Mounting System

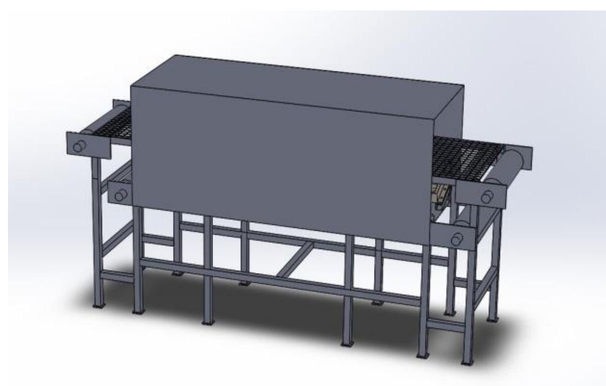

Figure 2: Final Design of Prototype

When first constructing the prototype, our first approach was using bolted technique to connect the intersection of each piece. However, this technique was not only very time consuming, but also took a lot of work. Thus, we took an alternative approach using tungsten inert gas (TIG) welding. This method allowed us to quickly assemble the design. It also provided a strong and sturdy base structure. Next, the rollers were attached to the bearing screwed onto the metal plates. The motor was screwed in onto a mounting system which was attached to the legs of the prototype. The conveyor belt was put into the system and then attached to the tensioner in order to function correctly. Finally, an insulation box was used to enclose the entire system in order to prevent heat loss and provide a surface for the reflection of radiation within the system.

Throughout this project we did three different experiments. The first was a static experiment. We tested 20 small 330 mL cans and 20 big 500 mL cans both for 7 seconds and 46 seconds. From our data we found that there is not a significant difference between the small and big cans' drying percentage, so it is not necessary to test both cans as we move on to further experiments. This also gave us a control value of 42% drying percentage as we move forward to angle testing to find the most drying efficient angle to place the infrared tubes at. Our next experiment was testing different angles of the infrared course tubes. After the mounting system was constructed for the tubes, we were able to test the tubes at 15, 22, 28, and 35 degrees. We tested 20 small 330 mL cans for 7 seconds and did 5 trials. We found that 35 degrees was the most efficient angle for drying so once we build our prototype we will conduct tests with the infrared tubes being at 35 degrees. Our final experiment was a dynamic experiment where we tested 20 small 330mL cans going through our prototype for 7 seconds with the tubes at 35 degrees. From our data we found that the average drying percentage of the cans after going through our drying process was 44%. The 44% drying percentage shows that if our Step 1 is implemented onto the production line at Pacific Can, the drying ovens will only need to operate at 56% of what they used to, which in turn should cut energy usage and costs.

In order to see how much Pacific Can would save from using our Step 1, we used Cost Benefit Analysis (CBA). This approach estimates the strengths and weaknesses of alternative solutions by comparing requirements and possible net outcomes. Our Step 1 replaces 45% of the existing convection drying ovens. Due to this, Pacific Can saves $589.05 if our Step 1 is added to one of the 3 production lines at the Pacific Can factory. This proves that adding an infrared drying system is a safe investment and will have positive outcomes.

Overall our team is very pleased with the outcomes of our project. We were able to successfully advance the previous MQP's project by creating a dynamic model of our solution and doing further tests to get more accurate data about our solution. If this project moves forward with another MQP group, we have several recommendations to consider. These are:

1. Use 5-7 thermocouples within the system to determine if the heat is spread evenly throughout the system.
2. Add a voltage regulator to the infrared tubes to conserve energy
3. Use more cans in future experiments
4. Test more angles for the infrared tubes from 0 to 55 to find the most drying efficient angle
5. Check Pacific Can for materials before ordering materials on your own
6. Add one more roller to the prototype to create an S shape in the conveyer belt to drive the conveyer belt more successfully
7. Look into waterproof infrared tubes
8. Investigate better insulation methods for the prototype

1. Introduction

Companies worldwide have begun to realize the impact of their production on the environment. Executives from 13 major U.S corporations are announcing at least $140 billion in new investments to decrease their carbon footprint. (Sink, 2015). Several big name companies like Coca-Cola have pledged to "drive down the carbon footprint of its beverage production by 25% over the next five years". (Sink, 2015).

Aluminum can production is most common and viable way for companies to package their beverages due to its recyclability and efficiency. The major expense of beverage cans is the energy needed to produce the aluminum, but recycling can save up to 95% of the energy cost. (Woodward, 2016). Manufacturers around the world are looking towards lowering production costs while still being environmentally friendly. Our sponsor, Pacific Can, is one of these companies.

Pacific Can is the leading manufacturer of 2-piece aluminum cans for beverage packaging in China. (Pacific Can). The company is environmentally aware and looking towards decreasing its carbon footprint and lowering its energy consumption. They have identified a possible improvement in their drying process of their cans in their manufacturing line. A past Worcester Polytechnic Major Qualifying Project (MQP) team has researched infrared drying techniques and developed a few solutions for this process. Our team will analyze these solutions, investigate its costs, benefits, energy consumption, and credibility for the production line, test the solutions gathered, and implement the new drying process on one of Pacific Can's production line.

1.1 Defining the Problem

Aluminum can production is a long process that can be broken down into several steps. The step that our team is focusing on is the drying stage after the cans have been washed. Currently, most production lines have a 3 zone drying process, two of them being heating zones and one of them being a cooling zone. (Ball). The heating zones serve to heat up the cans so that the water residue left on the cans after they have been washed can evaporate. The cooling zone is to bring the cans back to ambient temperature.

This drying process is not environmentally friendly due to the power and energy consumption that comes with operating the ovens for this process. Our team's mission is to find an alternative solution to make this drying process more environmentally friendly while reducing costs that Pacific Can has from their current drying process.

Past MQP groups have worked on solutions on a small scale drying process using infrared lighting. This scale used up to 25 cans. Our team will consider past teams' recommendations and tweak it as we see fit in order to create this new solution in which Pacific Can will be able to later implement in their production line.

1.2 Goals

The goal of this project is to assist Pacific Can in creating an innovative Step 1 in their drying process of aluminum cans using infrared lighting to later be implemented on their current manufacturing line. This system must be energy efficient, environmentally friendly and reduce cost for this system to be feasible.

1.3 The Layout of the Complete Report

Introduction

In the introduction chapter, we started with defining the problems and goals in order to give readers some basic information about this project.

Literature Review

Literature review includes all the background researches before starting doing this MQP.

Objectives

In this section, we defines all the objectives that are necessary to begin this MQP.

Methodology

Methodology chapter introduces all the detailed information for each objective in the previous chapter.

Analysis

All the analysis about current process, cost and benefit, conveyer belt, materials and design will be included and specified in this chapter.

Experiments and Results

Assumptions, process and results of the three experiments will be introduced in this chapter. Also, a possible error analysis will be included at the end of this chapter.

Conclusion

Recommendations, future works and constrains will be presented in detail.

2. Literature Review

2.1 Innovation and Entrepreneurship

Innovation can be defined as a new idea, or more-effective device or process. (Innovation, 2016). It can also be viewed as “the application of better solutions that meet new requirements, unarticulated needs, or existing market needs”. (Maryville, 1992). We intend to use the knowledge we have from material we learned in class and experience in the work field and come up with a new environmentally friendly and cost efficient drying system for Pacific Can.

Entrepreneurship is the process of designing, launching, and running a new business, i.e. a startup company offering a product, process or service. (AK, 2015). Entrepreneurship can also be defined as the “capacity and willingness to develop, organize, and manage a business venture along with any of its risks in order to make a profit”. (Entrepreneurship, 2014). In our case, we intend to implement this environmentally friendly and cost efficient drying process into Pacific Can’s production line in the best way possible. In order to do so, we will review and use some of the recommendations from the previous MQP team who worked on this project and combine it with our own ideas.

The innovative idea will be environmentally friendly by being a way to decrease the energy consumption in Pacific Can’s aluminum can production process. It will also be cost efficient by being able to cut expenses of the power generated in order to complete the process since we will be using other means to dry like infrared lighting. We will use a Cost Benefit Analysis to determine if our innovative idea meets this goal.

We will have an entrepreneurship mindset throughout this process in the way that if this innovative idea proves to work properly and meet or exceed our goals, it can also be implemented in other Pacific Can locations. If the idea does not meet or exceed the goals, we will find the cause of the problems and tweak our idea into something that works. Our team can even look into other markets that would benefit from this innovative drying process and work with them to implement it.

2.2 Aluminum Can Production Process

The general aluminum can production process can be split into 15 stations.

Station 1: Uncoiling

The aluminum can coils arrive at the production line. These coils weigh 10 tons, and are 5 feet in diameter and as thin as construction paper. This roll is long enough to make 750,000 cans. The coils go through an uncoiler that unrolls the strip of aluminum at the beginning of the production line so that the strip can be lubricated. The lubrication allows the aluminum flow to be smooth for the next step.

Station 2: Cupping Press

The cupping press cuts circular discs 5.5 inches in diameter from the aluminum sheet and forms them into shallow cups. The cups are then dropped onto the conveyer. This operation is performed at high speeds and make 2,500 to 3,750 cups per minute. The scrap aluminum that is left over is removed and recycled.

Station 3: Forming Higher Cups

The cups are then drawn up into higher cups through a series of iron rings. This makes the aluminum look like a can.

Station 4: Trimming

The tops are then trimmed off to make them all even with the same height and width.

Station 5: Washing

The cans then go through a washer which cleans and dries the can bodies in order for them to be decorated. Most manufacturers use a six stage washing process using either hydrochloric acid, sulfuric acid, or patented solutions in the first two stations and using deionized water in the last four stages.

Station 6: Printing

The cans are then sent to a printer where 6 to 8 colors of ink may be placed on a can at the same time. As the label is being applied the can is spinning. A coating is then applied to make the outside of the can shiny and protect the newly applied paint.

Station 7: Drying

The can then goes into an oven where the paint and coating are baked onto the can to prevent chipping. Different manufacturers use different techniques to dry their cans like hot air dryers, blowers, or ovens. Generally the temperature of the blowers is between 163 degrees Celsius and 190 degrees Celsius. The temperature for drying in the oven is generally 200 degrees Celsius for about 20 seconds.

Station 8: Internal Coating

The can’s inside is then coated with a spray to keep the metal from touching or reacting with the beverage that will be put in the can in the future.

Station 9: Drying and Sealing the Coating

The can is baked in the oven again to seal the coating onto the can.

Station 10: Flanging

The top of the can is then made narrow so that the lid of the can be placed on the can once it gets filled. The lip, or flange, is formed that will help seal the lid in place after the soft drink is put in the can.

Station 11: Reforming of Bottom of Can

The bottom of the can is then reformed. The machine makes a small dome that helps improve the strength of the container.

Station 12: Testing for Holes and Flange Cracks

All finished cans are then tested for leaks by sprinkling water onto the cans. A light tester can find holes smaller than human hair.

Station 13: Palletizing

The cans are then put on pallets. These pallets will be shipped to soft drink companies which will fill the cans with their beverages.

Station 14: Lids of Cans

The lids, or ends, of the cans are made and shipped separately to the soft drink companies. The end is also cut out from the coil of the aluminum after it is lubricated and is made into a round shell.

Station 15: Coating Shell and Tab

The shells are coated with a sealant and dried in order for the soft drink not to touch the metal. A machine then makes a button on the end where an easy-open tab can be secured in place. The tab is so that you can open your soft drink by pulling up and pushing the tab back.

2.3 Physical structure of the drying unit

For the drying unit, we expect a strong structure that could hold the infrared tubes and thousands and hundreds of soda cans at all time. Also, the material we are using would be able to have high service temperature and high radiation reflection to help perform better efficiency. We hope to reflect as much radian as possible back to the soda can. After searching the CES Edupack 2015, it would be a good idea to have at least two layers for the physical structure of the drying unit. Both two layer should have high service temperature. At the same time, the outside layer should also have high yield strength while the inside layer should have high radiation reflection. The following three figures will show the plots from CES Edupack 2015.

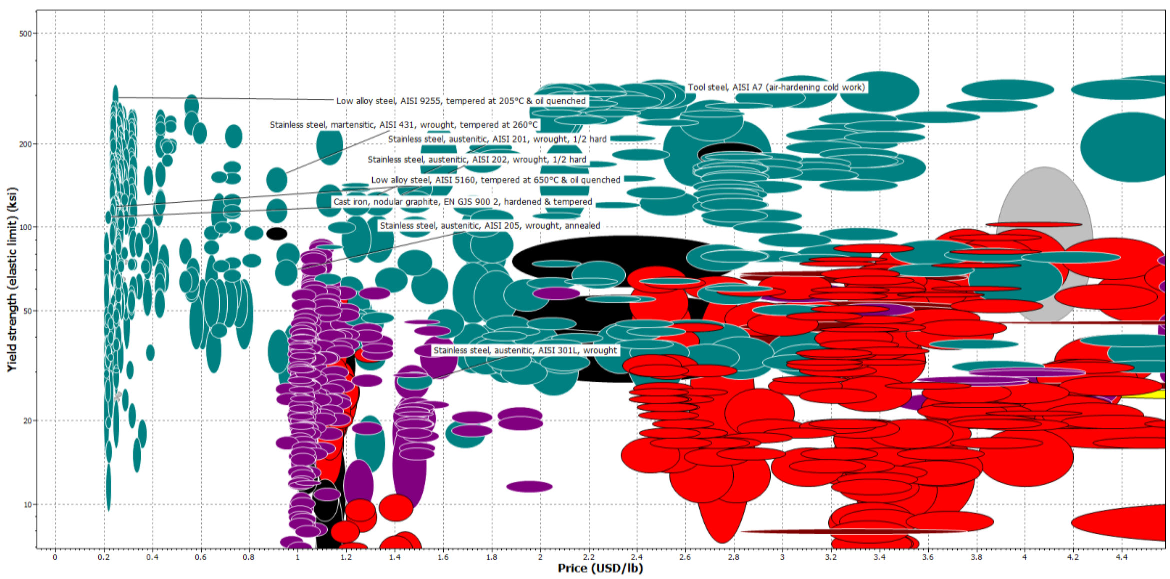

Figure 3: Material Price vs Yield Strength

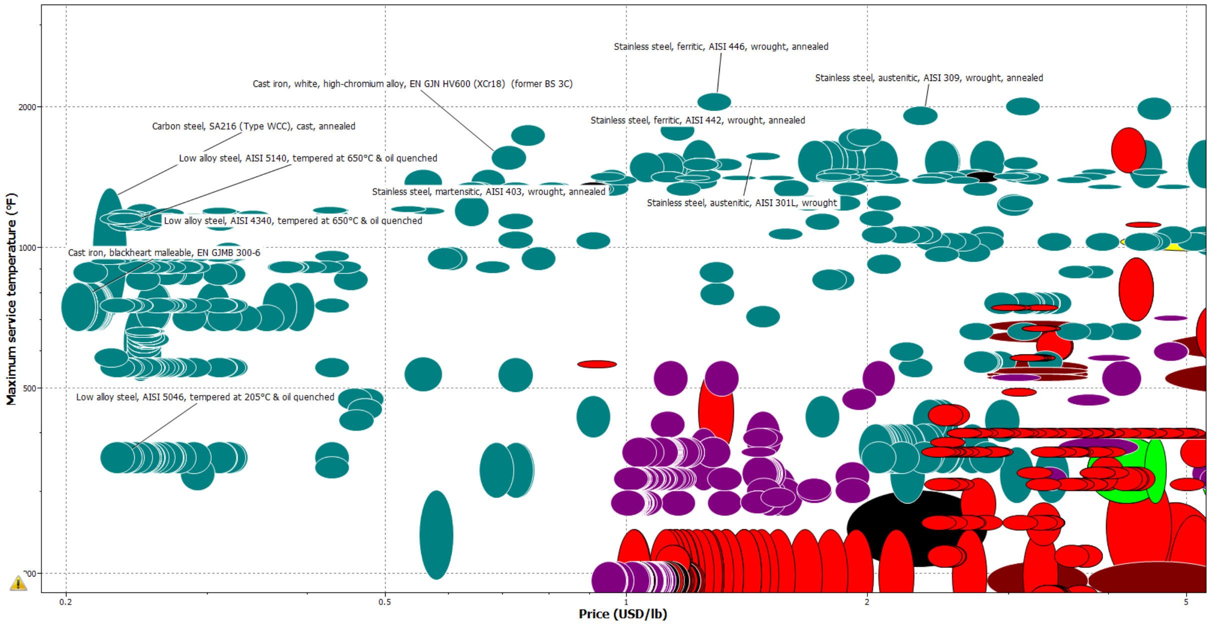

Figure 4: Material Price vs Maximum Service Temperature

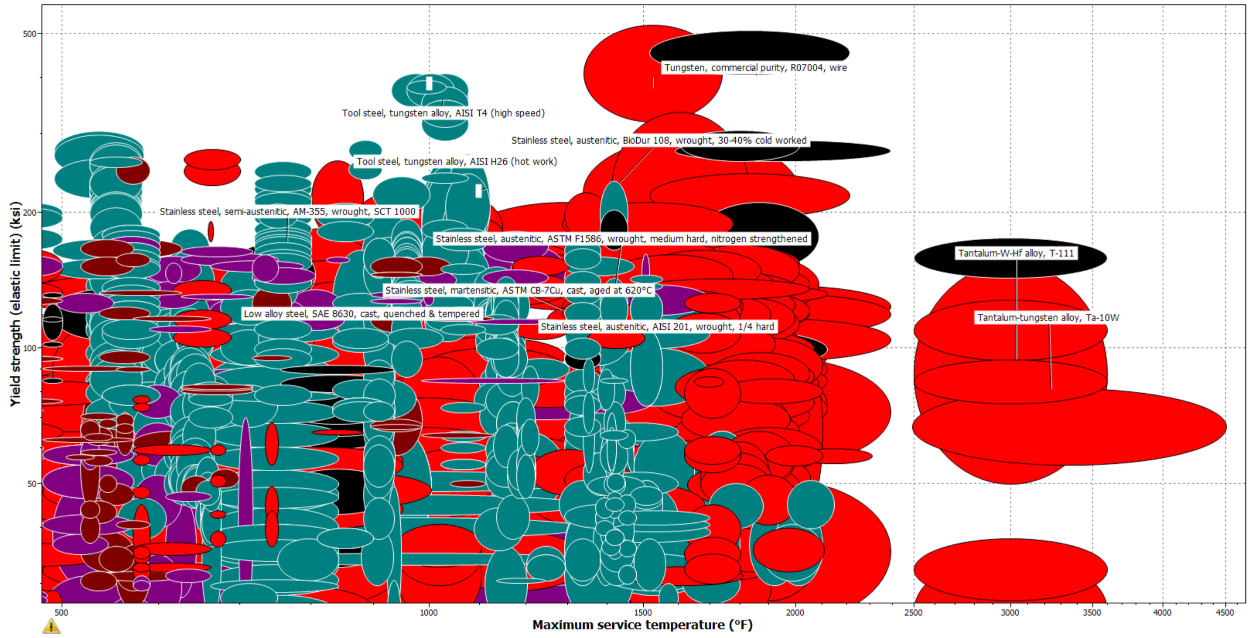

Figure 5: Material Maximum Service Temperature vs Yield Strength

According to the figures shown above, tantalum and stainless steel would be the ideal material for the outside layer. By comparing price of two material, we can make conclusion that stainless steel should be selected because of the low price and the strong mechanical properties. For the inside layer, we may use a thick aluminum to reflect the radiation from the infrared tubes.

To ensure the drying unit is energy efficient, our team must insulate the drying unit to reduce heat loss during the time frame that the infrared quartz tubes are running.

2.4 Infrared Energy

Unlike visible light waves that allow human eyes to easily detect, infrared energy cannot penetrate Earth's atmosphere and be detected on the surface. Infrared energy along with these visible lights and other forms of radiation like x-ray, gamma ray, microwave...etc. make up the Electromagnetic Spectrum, which is the complete spectrum of radiation.

The major difference between all these forms of radiation is their wavelength. The wavelength of infrared energy is measured in microns (mm) and ranges from 0.70 mm up to 1000 mm, which lies between visible light and microwave on the electromagnetic spectrum. It has longer wavelengths than visible light and shorter than microwave; lower frequencies than visible light and higher than microwave. Also, we encounter infrared energy on a daily basis but are unaware of it most of the time because of infrared energy's invisibleness. Through changing the dipole moment, infrared radiation excites the vibrational modes in a molecule, which makes it a useful frequency range to study these energy states.

Infrared heating delivers and transfer thermal energy through electromagnetic waves; through changing the dipole moment, infrared radiation excites the vibrational modes in a molecule, which makes it a useful frequency range to study these energy states. The transfer of infrared energy is emitted or radiated from the heated object, which is one of the three ways to transfer heat; the other two are conduction and convection. The source of heating emits radiation at a peak wavelength onto another object, and allows it to absorb the radiation at certain wavelength (others being reflected or re-radiated) to create heat.

Certain characteristic such as efficiency, wavelength, and reflectivity varies infrared heating to a certain respect. Although the wavelength of infrared energy ranges from 0.70 mm to 1000 mm, the actual useful application falls within 0.7 mm to 10 mm, which is categorized into 3 specific term: short-wave, medium-wave, and long-wave. The medium and long-wave have the most practical and useful application for industrial uses since most objects being heated provide maximum absorption in the region of 3 to 10 mm.

2.5 Application of Infrared Energy and Types of Infrared Heaters

Infrared heaters come in many forms and types, but there are 4 types that are most applicable for both industrial and daily uses, including ceramics elements, quartz tubes, quartz lamps, and metal-sheath elements. All these types of heaters are useful in different aspects; however, it is more important to note the differences among them rather than the similarities.

Ceramic elements heater is suitable for process that requires an oven that produce gentle and more distributed heat. Of all 4 types of heaters, ceramics elements is the most efficient one in converting electricity into infrared heat with a 96% infrared efficiency. Moreover, ceramic emitters has excellent life span and durability, offers zone control while heating, and works effectively with emissivity of the material. On the other hand, it has the lowest maximum operating temperature, 1292∘F (700∘C), compare to others, and has slow response time in reaching maximum temperature.

Quartz tubes heater is best suited for application that requires radiation to be on and off instantly because of its fast response time to reach maximum temperature. Quartz tubes can reach up to 1600∘F (871∘C) for the maximum operating temperature, and has a good life span as well.

However, quartz tubes heater has only 61% infrared efficiency and a poor durability. The heater also does not work effectively with the emissivity level of the material.

Quartz lamps heater is very similar to quartz tubes heater in many ways, it is best used in radiant application that needs instant on and off because of its ability to reach maximum operating temperature at 2500∘F (1371∘C) almost instantly. Quartz lamps heater is also made in high watt density, thus, most effective for high speed production process. In addition, it has a good overall life span, and 85% infrared efficiency, being the second highest of all 4 types of heaters. However, Quartz lamps heater has poor durability and a higher cost than other, and is difficult to be installed.

Metal-sheath elements heaters is best suited for convection application like electric household ovens. Comparing to quartz tubes and lamps, metal-sheath elements heater is very much like ceramic heater that has a slow response time in reaching maximum operating temperature. However, it has excellent durability and lifespan, and can be easily installed.

For this project, we will be using quartz tube heaters. Quartz Tube Heaters are the most ideal one to fit in the system and the design for several reasons. The price of quartz tube heaters are within a reasonable range; they have an overall good lifespan and durability, and an efficiency of 61% to convert electricity into infrared radiation. Most importantly, they have fast response time to reach maximum operating temperature. This feature can reduce operating cost because once the system reaches optimal temperature the infrared quartz tube can be shut off and start once more to reach optimal temperature once the optimal temperature begins to drop.

Table 1: Comparison of heating options

	Ceramic Heater	Quartz Tubes	Quartz lamps	Metal

				Tubulars
Response time to reach maximum temperature	Slow	Fast	Instant	Slow
Lifespan	Excellent	Good	Good	Excellent
Durability	Good	Good	Poor	Excellent
Infrared Efficiency	96%	61%	85%	56%
Maximum Operating Temperature	1292°F (700°C)	1600°F (871°C)	2500°F (1371°C)	1400°F (760°C)
Installation Difficulty	Moderate	Moderate	Difficulty	Easy

2.6 Heat Transfer

During the drying process of aluminum can manufacturing, heat transfer is an important component that needed to be examined and closely monitored. That being said, the transfer of thermal energy from the infrared tubes will determine the time to completely dry the aluminum can and the amount of energy and power consumed, which is correlated to the cost. There are three types of heat transfer: conduction, convection, and radiation. In this process, two of the three types, convection and radiation, will be the primary methods to transfer thermal energy onto the aluminum can.

2.7 Radiation

Radiation is the transfer of heat in the form of electromagnetic waves without any material medium. All forms of matter (from solid phase to gaseous phase) that surround us emit radiation, including furniture, walls, and living matters. Specifically, any matter that is above 5 degrees Kelvin (minus 268 degrees Celsius) will emit infrared radiation. Therefore, the infrared tube emit heat onto the aluminum can as they are transported through the conveyor belt.

In order to calculate the thermal energy of radiation we first find the emissive power, E.

$\boldsymbol{E = \varepsilon\sigma T_s}$ (eq1)

- **Ts** is the surface temperature in Kelvin
- $\boldsymbol{\sigma}$ is Stefan Boltzman constant ($\boldsymbol{\sigma}$ = $5.67 \times 10^{-8}\ W/m^2 \cdot K$)
- $\boldsymbol{\varepsilon}$ is the emissivity of the material ($0 \leq \boldsymbol{\varepsilon} \leq 1$)

In addition, the surface of the object may also absorb a portion of the irradiation, in which will increase the thermal energy. The rate of the radiant energy absorbed per unit surface area is evaluated with the following equation:

$\mathbf{G_{absorbed} = \boldsymbol{\alpha}\ G}$ (eq2)

- $\boldsymbol{\alpha}$ is the absorptivity ($0 \leq \boldsymbol{\alpha} \leq 1$) $\Rightarrow$ if $\boldsymbol{\alpha} \leq 1$, surface is opaque

However, in many cases, the radiation exchange of thermal energy happens between a small surface and a larger isothermal surface that surrounds the smaller one entirely. Thus, in this case, the irradiation is approximated by a black body's emission.

G= $\boldsymbol{\alpha}$ $(T_{sur})^4$ (eq3)

-T_{sur} is the temperature of the surrounding environment

Therefore, combine the emissive power and the irradiation, the net radiation can be evaluated as follow: $Q= (q/A) = \varepsilon E(T_s) - \alpha G = \varepsilon\sigma\ ((T_s)^4-(T_{sur})^4)$ (eq4)

2.8 Convection

The transfer of thermal energy through convection occurs between the surface and a moving fluid that are both at different temperature. That being said, the energy is transferred by the moving fluid, which is associated with the collective number of molecules moving as aggregates, in which transfer heat onto the object. For our case, the moving fluid will be the static air in the system, which act as a medium for the transfer of thermal energy from infrared tube to the aluminum cans.

The appropriate rate equation to calculate the heat transfer through calculation would be

$Q= h (T_s - T_\infty)$ (eq5)

- Q is the convective heat flux (W/m^2)
- T_s is the temperature of the object's surface
- T_∞ is the temperature of the fluid

2.9 Heat of Vaporization of Water

The purpose of the drying process is to remove any residual water droplets remain on the aluminum cans; thus, it is important to know how much energy the water need to absorb in order for it to vaporize in this process. According to heat of vaporization, the energy required can break down the intermolecular attractive forces and convert water from liquid state into gaseous state per gram at the boiling point; with the equation:

$Q= m H_v$ (eq6)

- Q is the total heat
- m is the mass of water
- H_v is the heat of vaporization, which is 2260 J/g at 100∘C for water

2.10 Longevity of Infrared tubes

After consideration, we think that implement a water-proved infrared tubes would help improve the manufacturing line in a long term. Before the cans enter the drying unit, they are washed still with some drops on the cans. During the drying process, those drops may fall down on the infrared tubes, which may be possible to destroy or affect the efficiency of the working infrared tubes. Shutting down the production line to replace damaged infrared tubes, will cost Pacific Can unnecessary time and money. Overall, when selecting the material for the infrared tubes, we consider that it would be a good idea to choose a water-proved infrared tubes to have a long-lasting and well-working infrared tubes.

2.11 Decreasing the humidity inside the drying unit

As the massive cans are dried through the process, the water drops will be heated to become steam and rise up to the top of the drying unit. As a result, the efficiency of the whole process will be lowered down because of the increase of the humidity inside the drying system. We think of two options to decrease the humidity. One is adding a fan on the top to help the steam flow throughout the drying unit. However, this may decrease the efficiency of the drying process because of blow heat out of the system. The other is adding a condenser system on the top of the drying system. The steam will enter the condenser system to be cooled down as water. After that, those water could be reused into the washing process to save water and energy sources.

3. Objectives

In order to complete our project in seven weeks, we broke down our project into steps. These steps are:

1. Analyze current drying process at Pacific Can
2. Analyze previous groups recommendations
3. Test previous groups experiments to compare data
4. Create Solidworks models for our part in the drying section
5. Test angles for infrared lighting
6. Build prototype
7. Test prototype

4. Methodology

4.1 Analyze current drying process at Pacific Can

Figure 6 shows the flow diagram of the current can making process: copper, body maker, washer, decorator, pin oven, lacquer spray machine, internal bake oven, waxer, necker, flanger, light tester and palletizer.

Figure 6: Pacific Can flow diagram

The drying process we are adding a step to is right after the washing step. We will also analyze the washing process to see how wet the cans are after being washed and the process of the cans getting to the drying step. This will give us a general idea about how to build the prototype with the infrared tubes. In addition, we will be analyzing the speed of the conveyer belt and the dimensions of the space given to us to implement the first step in order to use this information when we create our SolidWorks designs of our prototype.

4.2 Analyze previous groups recommendations

It is important for us to understand the work of the previous MQP so that we could get a better understanding of what the problem is, what has been done already, and what still needs to be done. The previous team recommended to do the experiments with more cans or with different sizes of cans to determine the best temperature control for the infrared tube system. They also mentioned in their report that waterproof infrared tubes should be considered as a better choice for the experiments and production line due to the excess water dripping from the cans. Currently, due to the budget and the equipment we have available in the lab, we decided to use a mesh screen on top of the infrared tubes to prevent the water drops from destroying the tubes. Once the company decides to implement this drying system on the production line, we will recommend for them to buy the waterproof infrared tubes.

The previous MQP used infrared tubes to dry a small batch of aluminum cans by inserting 25 aluminum cans in an infrared enclosure they created. We redid their experiments with different sizes of cans to get more comprehensive data. Due to them testing 25 cans, the entire middle column was not receiving any infrared light. Therefore, we reduced the number of cans in a row for the experiments to make sure that every can will be exposed right on the infrared tubes to get the most heat from the radiation, as it would occur on the production line. As long as we could make the conveyer belt work properly, we will be able to do tests with more cans moving on the belt.

The infrared enclosure they created was composed of two quartz infrared tubes encased by an aluminum housing unit. The prototype developed by the last MQP team was not insulated well, so our team will add a layer of insulation in our housing unit design. The previous improvements listed among others will allow our group to improve the prototype and implement it on the manufacturing line.

4.3 Test previous groups experiments to compare data

In order to get a better understanding of what was done in the past group and how they got the results they did, it was important to re-do their tests. There was a gap between their tests and what goes on in the production line at Pacific Can. The past group tested the amount that the cans would dry by placing about 1 mL of water on the top of the cans and putting it in their enclosure for 50 seconds and then testing hoe much water was left on the cans. In the production line, after the cans come out of the washing station, air is blown on the top of the cans to get rid of the excess water. The cans are then lifted by a vacuum system and taken to the drying section. If cans still have excess water on the top, then they will be too heavy for the vacuum system to pick up and they drop in a basket for recycling and go through the process all over again. Once the cans get into the drying system, the inside of the cans are the part that is wet, so out experiments are going to be focused on drying the inside of the cans, not the top.

The past group also used 10 seconds and then 50 seconds as the set time that the cans were in their proposed drying system. These numbers do not match with how long the drying process is at Pacific Can. Using the speed of the conveyer belt and the length that our new section would be in Pacific Can, we calculated that the cans would go through our step for approximately 7 seconds and would be in the whole drying system (our part and the drying oven) for a total of 46 seconds. Due to this, we will use 7 seconds and 46 seconds for our static and dynamic experiments with the aluminum cans.

The experiments from last year only used one type of can, which is not the case on the production line at Pacific Can. Depending on the order inquiry that Pacific Can gets, they could be producing cans ranging from 355 mL to 500mL. In order to account for this range, we will run experiments using small and large aluminum cans to make sure that our new proposed process works for all types of aluminum cans that Pacific Can will be producing.

Our experimental procedure will be different than the past group because of all these differences, so our results will most likely differ as well. However, we will use the same way of calculating the drying percentage of the cans by weighing the can before getting washed, after getting washed, and then after its in our drying system for a certain amount of seconds (either 7 seconds or 46 seconds). To calculate the drying percentage we will use this formula:

$$\frac{(\text{weight of can w/ water} - \text{weight of dry can}) - (\text{weight of can after 7 sec} - \text{weight of dry can})}{(\text{weight of can w/water} - \text{weight of dry can})} \qquad \text{(eq7)}$$

4.4 Create a SolidWorks model of our drying section

The previous MQP team developed a static Solidworks model of a prototype of an infrared drying structure. After analyzing the work of the previous MQP team, our team decided to compose a dynamic SolidWorks model. This model will aid our iteration process when designing the next rendition of a prototype. Achieving this step before visiting Pacific Can is imperative to ensure our team has a viable solution allowing us to produce a prototype in our first few weeks in China.

In order to install the infrared quartz tubes within the conveyor belt system, we created a SolidWorks design of the mounting system for the tubes. (Figure 7). The grey parts are the main structural support and the light brown part is the infrared quartz tubes. The infrared quartz tubes we are using are made out of glass and are not water proof. Due to this, we cannot afford to let the water droplets hit the tubes directly as it would destroy the tubes. We then came up with another design of the mounting system (Figure 8). The second design of the mounting system is 7 x 8 x 25.5 in^3, allowing the quartz tubes to be positioned at different angles (15°, 25°, 35°, and 45°) instead of being parallel with the cans. In addition, a window mesh screen is placed onto the quartz tubes. The mesh screen will be directly heated up by the quartz tubes and reach a high temperature;

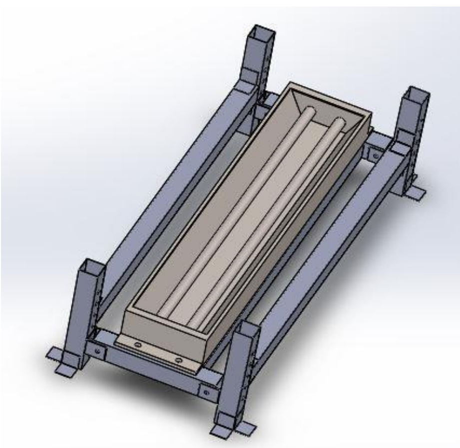

Figure 8: First Design of Mounting System

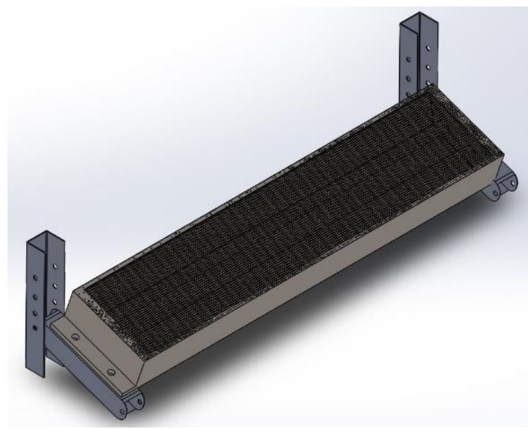

Figure 7: Second Design of Mounting System

therefore, as the water makes contact with the mesh screen, a portion of the water will evaporate immediately. The mesh screen will also change the water droplets' direction and prevent it from having direct contact with the tubes.

The first Solidworks design for the conveyor belt system we created (Figure 9) was the most ideal one in terms of structural support, appearance, and functionality. Our conveyor belt system is essentially made out of 2 tables and having them being connected together. The taller table provides a flat surface and support for the conveyor belt to transport the aluminium cans. The smaller table allow us to install the quarts tubes right underneath the aluminium cans as they are being transported. Then the conveyor belt will be connected by four rollers forming in a trapezoid shape.

Due to the limitations of our budget and the cost of materials, certain parts such as the plates with holes at the top, and the long plates on both sides were very expensive to purchase (costing approximately 1,700 RMB for each part). Also, the Omega-shaped bearing attached to the roller was difficult to be custom made.

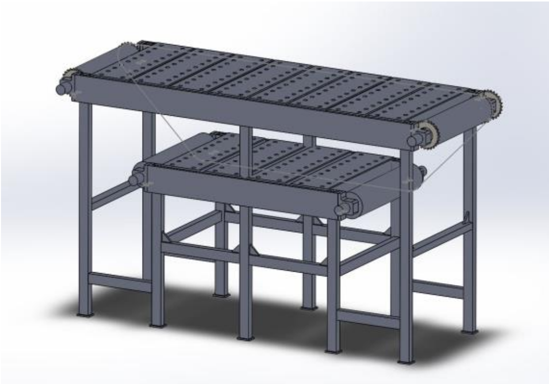

Figure 9: First Design of Prototype

Thus, we took a different approach and came up with an alternative design (Figure 10). The second design got rid of all the expensive parts; instead we replaced the structure with mostly 3cm x 3cm stainless steel square stocks as the main structural support of the system, along with several 26.67 x 10.16 cm^2 metal plates as side support. The surface of the two tables were replaced by 2cm x 5cm rectangular stocks. We also increased the total length of the system in order to have enough space to install 4 infrared quartz tubes underneath the conveyor belt (Figure 11).

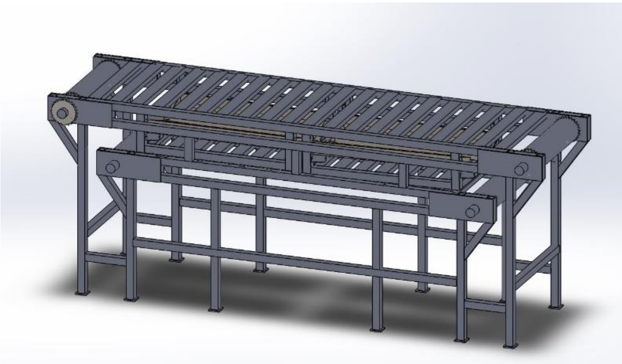

Figure 10: Alternative Design for Prototype

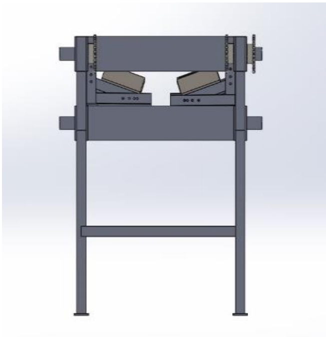

Figure 11: Side View of Alternative Design

However, while building the prototype, we struggled to build certain parts because they were difficult to be put together. Thus, we had to modify the design and included some changes such as adding a metal net as the bigger table's surface (Figure 12), a tensioner on the bottom right roller (Figure 13), and finally a containment box for insulation purpose (Figure 14).

In order to allow the infrared radiation to get through and dry the inside of the aluminium cans, the surface of the table cannot be solid and needs to let the cans have as much exposure as possible to the radiation. Therefore, the metal net was selected. The bottom right roller was chosen to act as a tensioner. The plate attached to the roller has vertical movement in order to increase the total length and tension of the conveyor belt. As the belt is tensioned, the roller itself will create friction with the belt and drive the whole system. The insulation containment box will act as an oven; it will not only prevent a great amount of heat loss, but also provide heat reflection onto the cans to dry faster.

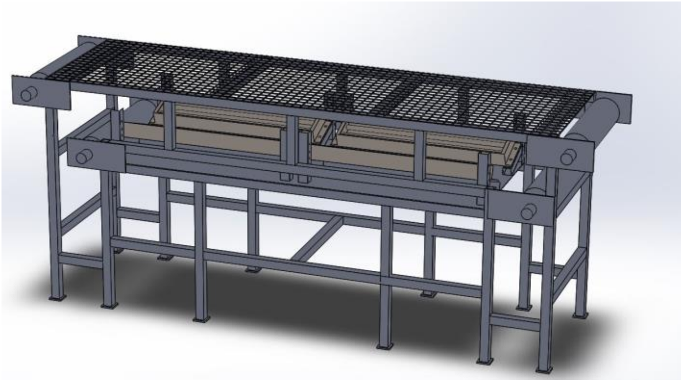

Figure 12: Final Design of Prototype

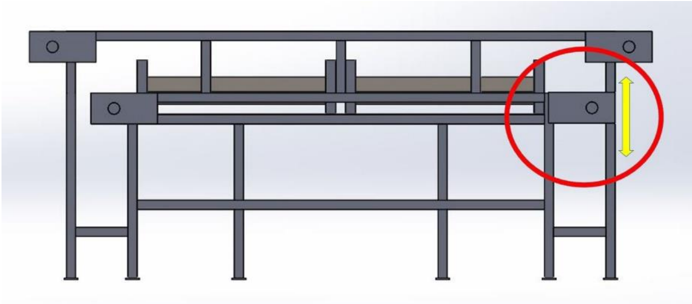

Figure 13: Tensioner on Bottom Right Roller

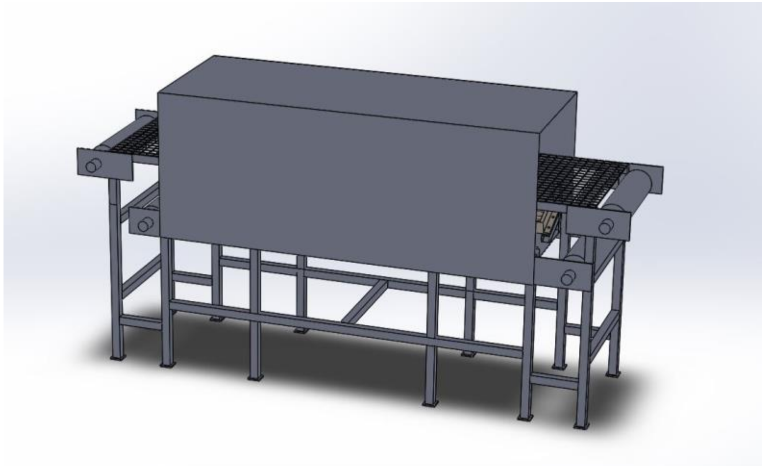

Figure 14: Insulation Enclosure over Prototype

4.5 Test angles for infrared lighting

In order to create our innovative drying process, we had to come up with a new design. We had to consider the location of the infrared lights in the system. We considered putting the tubes on top of the cans, below the cans, and on the side of the cans.

After examining these options we came to the following conclusions:

- If the infrared lights are above the cans, the heating waves will not reach the inside of the cans as the cans are upside down when they are going through this process and bottom lid is on.
- If the infrared lights are on the side of the cans, the same problem occurs as the infrared lights being on top.
- If the infrared lights are on the bottom of the cans, we need to make sure the conveyer belt is not blocking the cans from the infrared lights.

We ultimately felt that having the infrared lights below the cans was the best option. We then considered putting them at different angles ranging from 0 degrees to 45 degrees to get more reflectivity in the box and a faster drying rate than no angle. In order to find the best angle for the infrared lighting, we will test the drying percentage of different angles to see which is most efficient.

4.6 Build Prototype

The main material for the structural support of our prototype is 3cm x 3cm square stocks. When building the conveyor belt, we had to cut each part for the desired length first. In order to do so efficiently, we labelled each part with a number so it is easier to distinguish each piece.

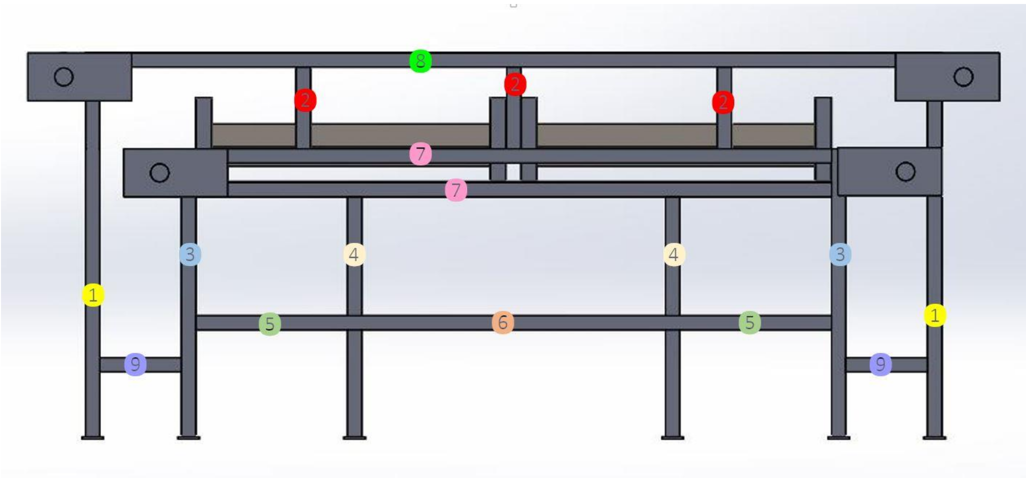

Figure 15: Prototype Square Stocks

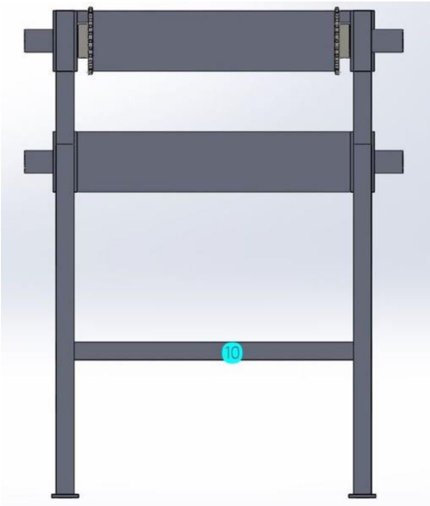

Figure 16: Side View of Prototype

Next we created a table with each part we needed to cut, its length in centimeter, and the quantity of these parts we need to cut (see Table 2).

Table 2 Squarestock parts of prototype

Part #	Dimension (cm)	Quantity
1	81.28	4
2	17.31	4
3	60.96	4
4	50.80	4
5	32.16	4
6	64.31	2
7	134.62	4
8	175.26	2
9	17.31	4
10	46.89	3

After all the square stocks pieces were cut, we then started to assemble the base structure. We first tried drilling holes with a 1 cm diameter and attaching screws and L-brackets at the conjunction. However, this method was very time consuming and required a lot of effort; considering each part needs to have multiple multiple holes drilled, and dozens of L-brackets needed to be cut. In addition, it did not offer a strong and stable support for the base structure which is needed due to the weight of the roller and other parts which can easily put too much strain on the whole body. Therefore, we took an alternative approach using tungsten inert gas (TIG) weld with argon gas. This method allowed us to complete the base structure more efficiently with less effort. TIG welding not only offers a stronger and more steady support when connecting the stainless steel square stocks together, but also enabled us to align each part and position them straight and normal to the ground.

After the square stocks were welded together, we then welded the 0.01 mm aluminium flat sheet onto the smaller table. The flat sheet acts as the surface for the smaller table for the infrared quartz tubes to sit on. Next, we welded the metal plates, which support the roller, onto the whole system. We then screwed in bearings and added the rollers. As the rollers were put in place, we welded the metal net onto the taller table. At this point, the basic structure of the conveyor belt was almost finished, but certain parts were missing that were necessary to be put in to complete the system.

Figure 18: Building Structure of Prototype

Figure 17: Building Prototype

Figure 19: Prototype Structure Built

Next, the motor was installed to the system. Provided by our sponsor, Pacific Can, the motor is a 3-phase induction motor with a spin rate of 1380 rev/min and powered with 220 Voltage. Ideally, the motor should be placed right beneath the smaller table of the conveyor belt; however, not enough space was available for the motor to be placed in because the smaller table was built too low. Thus, a motor mount was built with pieces of L-channel welded together, and attached to the side of the whole system. The motor was then screwed onto the mount.

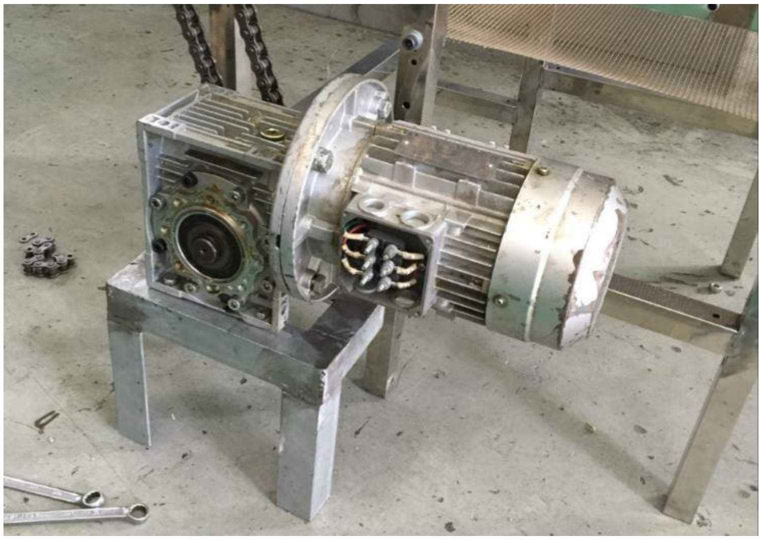

Figure 20: Motor Used

Next, the conveyor belt was put in, which was also provided by Pacific Can. It is a PTFE coated conveyor belt, which can sustain high temperatures. After the belt was placed in, we then lower the tensioner, which completely tensioned the belt in order to allow it to create enough friction with the roller.

Figure 21: Conveyer Belt Used

Lastly, in order to prevent potential heat loss and allow the radiation to reflect within the system, an insulation containment box was installed right on top of the conveyor belt. We first cut the desired dimension of the aluminium sheets, then folded it into a U-Shaped box. Since this box covers both the smaller and the bigger table, the insulation has a width that encloses the table perfectly, a length of 140 cm that covers up the entire smaller table, and a height of 55cm allowing both 330ml and 500 ml cans to have enough space to be transported through.

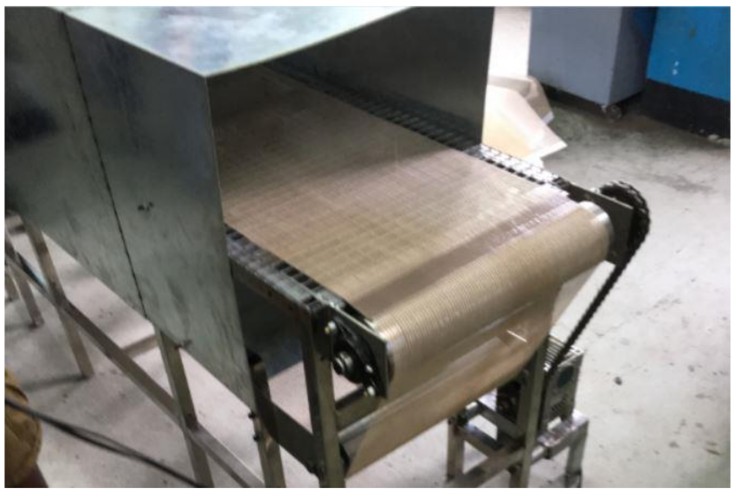

Figure 22: Enclosure Installed in Prototype

4.7 Test Prototype

Once we have our final prototype built, testing needs to be done to see the drying percentage that our step would have if implemented into Pacific Can's production line. Once we see what the drying percentage will be, we will be able to calculate the amount of energy and costs that Pacific Can will save by using our system and less of their oven system.

Before conducting our prototype experiments, we should have data from our previous static and angle experiments to guide us. The data from our static experiments should give us a control value of about what the drying percentage for each type of can (small and big) will be using the infrared tubes at zero degrees. This control value should be used as a comparison when we get the values for the drying percentage of different angles for the infrared tubes in our angles experiments. This comparison will allow us to find the most efficient infrared angle to be used which in this case is the angle that the drying percentage is the highest. From that data, we will know exactly what angle to put the infrared tubes at in our prototype experiments. The static experiment will also allow us to see if there is a noticeable difference between the drying percentages of the small cans versus the big cans. If there is a significant difference, both types of cans will have to be tested in future tests like the angles test and the prototype tests. If the difference is insignificant, than only one type of can will need to be tested.

4.8 Timeline of Project

Table 3: Timeline of the project

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**
Visit Pacific Can							
Create/Edit SolidWorks Designs							
Order Materials							
Static Experiments							
Building Mounting Structure							
Angle Experiments							
Building Prototype							
Dynamic Experiments							

5. Analysis

5.1 Current Process Analysis

On our first day, we went to the company to analyze the production line. All the cans were washed with chemicals and pure water. Before all the cans would leave the washing process, there was an air system that would sprinkle high pressure air to the bottom of the cans, so that there will not be any excess water drops left on the bottom of the cans. To make sure that the bottom of the cans contain no water drops and does not have any kind of deformation, there was an air sucking system in between the washing and drying system. If there are water drops on the bottom of the cans, the cans would be too heavy to have the system lift it up and transport it into the drying oven. The cans with deformations on the bottom would also fall down from the system. Therefore, the production line would have all perfect cans ready to be dried.

Once the cans entered the drying unit, it would be transported through the oven and be dried by the hot wind flow, which is created from burning coal. The entire drying section was about 7.8 meters long and the speed of the conveyer belt was about 0.17 meters per second. Our section to add the infrared tube drying system would be right before the current drying oven, which would be about 1.27 meters long. The current drying process uses two stainless steel plates with cotton in between as the enclosure of the drying oven. This type of enclosure would be cheap and easy to make and helps to prevent heat loss.

We also noticed that the current drying process has a low working efficiency. This is due to them burning coal as their heating source, which lowers the efficiency. They also use an air system to blow hot wind through the burning oven to get to the drying oven, which allows for a significant amount of heat loss.

5.2 Cost Benefit Analysis

Cost Benefit Analysis (CBA) is an approach to estimating the strengths and weaknesses of alternative solutions by comparing function requirements and possible net outcomes. (Watkins, 2006). Calculating the CBA of our IR Dynamic drying system will determine if it is worth the initial investment. While CBA can calculate certain parameters to determine its worth, it is not enough to prove that our design is worth its initial investment. Therefore our team must calculate its Return on Investment (ROI) as well. Upon calculating the ROI, our team can further solidify that our IR Dynamic drying system is worth implementing on the current Convection Drying line.

The table below display operational cost associated with the drying ovens once aluminium cans have been washed. Beijing Pacific Can has three production lines, however this analysis focuses on two production lines.

Table 4: Operational Cost of Oven in CNY

Current Process	Daily Natural Gas Usage (.61 RMB per m^3)	Daily Cost CNY	Annual Nat. Gas Usage (at 315 days)	Annual Costs in CNY
Line 1	1,000	601	315, 000	189,000
Line 2	900	549	283,500	172,935
Line 1 motor	N/A	9.68	N/A	3,049.20
Line 2 motor	N/A	9.68	N/A	3,049.20
Total	**1,900**	**1,169.36**	**598,500**	**368,033.40**

Table 5: Operational Cost of Oven in USD

Cost of Current Process	Conversion Rate*	Production Lines	Daily Cost in USD	Annual Cost in USD (at 315 days)
Chinese Yuan (CNY)	1	Line 1 & Motor	91.65	28,869.75
U.S. Dollar (USD)	.150078	Line 2 & Motor	83.84	26,409.60
		Total	**172.59**	**54,318.48**

*Conversion Rate (July 1, 2016, XE.com)

Using data provided by the Manufacturer regarding operational wattage we calculated the approximate operating cost of the IR drying oven compared to the operational cost of natural gas heated drying oven. This Comparison will reveal that using infrared drying tubes is more energy efficient and cost effective than Convection Drying ovens.

Table 6: Operational Cost of Dynamic IR tubes System

Infrared Oven	Daily Electricity Usage (0.5375 Yuan/ KHW)	Annual Energy Consumption in CNY (at 315 days)
4 Infrared Tubes (1,000 watts each)	51.60	16,254.00
3 Phase Induction Motor (7.5 watts)	9.675	3,047.63
Total	**61.275**	**19,301.63**

Table 7: Operational Cost of Dynamic IR tubes System USD

Cost of Current Process	Conversion Rate*	Production Lines	Daily Cost in USD	Annual Cost in USD (at 315 days)
Chinese Yuan (CNY)	1	4 Infrared Tubes	7.74	2,436.10
U.S. Dollar (USD)	.150078	3 Phase Induction Motor	1.45	456.75
		Total	**49.19**	**2,894.85**

*Conversion Rate (July 1, 2016, XE.com)

Table 8: Return of Investment

	Daily Cost in USD	Annual Cost in USD (at 315 days)	Initial investment for Dynamic IR Tubes
Line 1 Convection drying oven	51.06	16,083.90	
Dynamic IR tubes System	49.19	15,494.85	$740.18
Difference	**$1.87**	**$589.05**	

Return on Investment

- ROI=$\frac{(Gain\ from\ Investement - Cost\ of\ Investment)}{Cost\ of\ Investment}$

- ROI=$\frac{(\$589.05-\$740.18)}{\$740.18}$= 20.41%

The IR dynamic system is designed to replace only 45 percent of the current drying process. While our design could not only accelerate the drying process if add prior to the existing Line 1 Convection Oven it would save Pacific Can $589.05 per year after 1.25 years. Pacific Can would save more capital if completely replacing the Convection Drying Oven. However, adding Infrared Drying units would still save Pacific Can money.

5.3 Conveyer Belt Analysis

The main structure of the conveyor belt is made out of 3cm x 3cm stainless steel square stocks. The reason in choosing this material is due to the limitation of material cost; square stocks are relatively cheaper than other materials required. Of the conveyor belt system, 10 parts of square stocks are required to build the base structure, and each with certain dimension and quantity. The system itself is composed of two tables, a taller one that act as a surface to support the belt, and the other smaller one provide another surface underneath the cans to support the infrared quartz tubes. The total length of the system is 205.75cm, with a width of 53cm, and a height of 81.3cm. The total area of the smaller table is 134.63cm x 53cm, which is just enough to fit 2 quartz tubes in both longitude and latitude direction with a total of 4 infrared quartz tubes underneath the belt.

Moreover, the surface selected for the taller table is a 180cm x 53cm aluminium net. The net offers a strong and stable support when placed onto the table. 4 rectangular stocks were placed evenly underneath the net in order to prevent any slacking from happening. We also needed a surface that allows the radiation to get through and dry the cans; therefore, material like this net which not only offers an excellent support but also provide enough openings that allow the cans to be exposed to the radiation is perfect for the system.

One of the rollers at the smaller table is installed differently. It was screwed in with the legs of the taller and smaller table. Straight slots were also drilled on the legs attached to the plate. In doing so, the plate has free vertical movement, and can be adjusted up and down in order to increase the total length and tension of the conveyor belt.

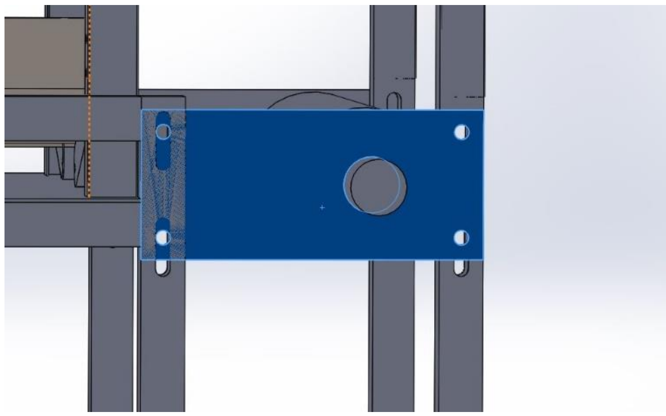

Figure 23: Tensioner Plate

The motor selected for the system is Y2-8024 series, an 11 kilograms 3-phase induction motor. It operates at 0.75 kW with 220 Voltage, and has a spin rate of 1380 rev/min. This motor provides exceptional features such as high starting torque, high efficiency, and is energy efficient. The terminal box is located on the top of the motor and its size and mounting dimension are a good match for our system.

Figure 24: Motor Used

The conveyor belt used was PTFE Coated Conveyor, which is composed of woven glass substrates, which offer exceptional strength and dimensional stability, as well as having a non-stick surface. It is designed to handle a high heat environment, and it can be operated at a temperature range from -73 degrees Celsius to 260 degrees Celsius. This type of belt is often used for application such as screen print dryers, drying textiles and non-woven materials, re-soldering and ink drying cable braiding. Thus, it is suitable for our drying system.

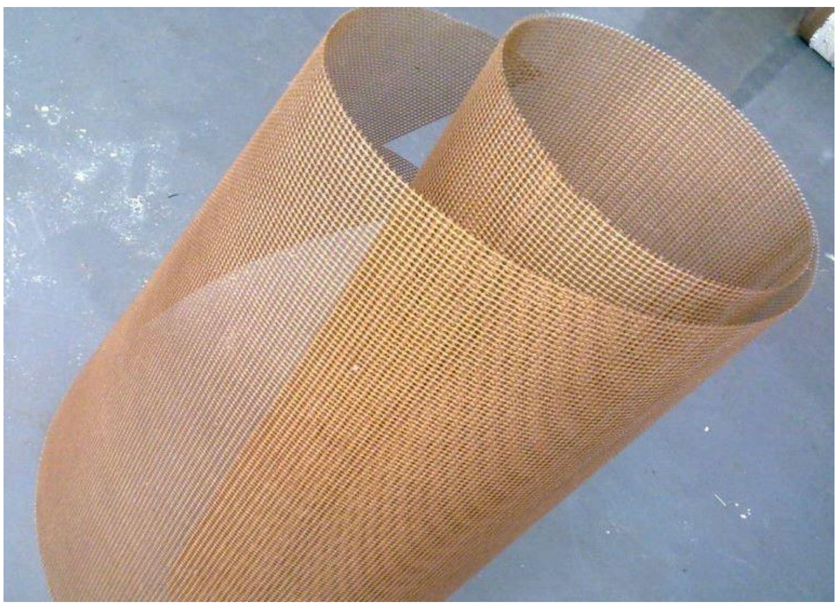

Figure 25: Conveyer Belt Used

The insulation system is essentially an aluminium box. Originally, our plan was to install 2 layers of aluminium and stuff asbestos in between in order to provide a greater heat insulation. However, the aluminium cans' will start to melt and deform at around 270°C. Considering that the quartz tubes provide a great amount of heat to the bottom of the cans already and the focus is not drying the top of the cans, we decided that 1 layer of aluminium insulation would suffice.

5.4 Material Analysis

The following is a list of materials that were selected to create our prototype with its dimensions.

Table 9: List of Materials Used

Name Of Material	Dimensions
Roller	**0.4064m (2) + 0.459m (2)**
L-shaped Bracket	**25mm X 18mm (20)**
Square Stocks	**30mm X 30mm X 2m (16)**
U-shaped Stocks	**Inner radius: 30mm X length 2.5m (2)**
Infrared Tubes	**2000W (2)**
Rectangular Stocks	**25mm X 50mm X 2m (4)**
Stainless steel plate	**1m X 0.6m X 5mm (1)**
Motors	**3000 RPM 12V**

For the material selection to build the prototype, we chose stainless steel for all the materials for the main structure. Like we mentioned in the background chapter, stainless steel has a great yield strength which allows the structure to be tough enough to hold up mass, which in this case would be the conveyer belt and the infrared tubes. It also has a high serving temperature, which would match the needs of the drying process as it will be constantly hot from the infrared tubes. To connect all the parts together, we used wielding and a pin. The melting point for the stainless steel we were using, is between 1399 degrees Celsius and 1455 degrees Celsius. Therefore, the metal we are using would not have problems with the working temperature of 220 degrees Celsius. Also, due to the high melting point, we were only able to do the tungsten inert gas (TIG) welding. For the supporting system, we use the stainless steel square stocks with the cross section of 30mm * 30mm because the square stocks would be able to hold the mass and is saved us from buying a lot of materials, which helped reduce the expense. In addition, L brackets were chosen to help fix the prototype and prevent the square stock structure from wobbling or collapsing. The whole structure with L brackets would be static and stable when the drying process is working. Additionally, the infrared tubes are mounted on standers made from square stocks and C channels. With these two materials, we were able to create a sliding mounting system for each of the infrared tubes, which may enable us to do the drying percentage experiments with different angles of the infrared tubes. For the conveyer belt, we chose stainless steel chain to transport the washed cans through the drying process because the chain sequence provides the wet cans with space to accept the radiation from infrared tubes and be heated up.

5.5 Design Matrix

Design Choice Criteria

We have chosen the Following criteria to compare our designs. The Criteria are:

- Cost
    - A design with a large cost will reduce the final Return on Investment (ROI)
    - Four mounting systems will be construct thus cost is major factor in deciding on final design
- Ease of Use
    - Adjusting the angle of IR tubes is the primary purpose of the mounting system, thus its important adjust the angles with ease
    - Design with higher scores tend to be more user friendly
- Versatility

- If the designs encompass more area then it will be harder test a variety of different orientation the Mounting system can fit in the conveyor belt system
- Designs with more versatility have a higher rating

- Size
  - The size of the design affects the cost. Larger designs require more materials. Designs that require less material have a higher score in the design matrix
- Degrees of Freedom
  - A design with degrees of freedom gives the more control during the experiment

Infrared Quartz tubes mounting system

Table 10: Design Goals decision Matrix

Design goals	Cost	Ease of Use	Versatility	Size	Degrees of freedom	
Weighted factors	90	85	65	60	40	Score
Design 1	4 360	4 340	7 455	4 240	7 280	1675
Design 2	8 720	8 680	5 325	8 480	6 240	2445

Adjusting Angle and position of Quartz Tube

In the previous experiments researchers set infrared drying tubes at zero degrees. While this approach did dry aluminium cans in a static experiment, our team believes this approach with present other challenges in a dynamic experiment. The primary challenge include wavelengths generated from the quartz tube may not be strong enough to reach aluminium cans on the perimeter of the lot. Thus leaving can on the perimeter significantly wetter than can in the center column of the lot. To rectify this issue our team plans place a pair infrared drying tubes at various angles face each other. This method will hopefully allow the quartz tubes wavelength to dry the entire lot. If this method is not as effective as hoped our team will change the orientation of tubes and angles till achieved the desired results.

Design 1

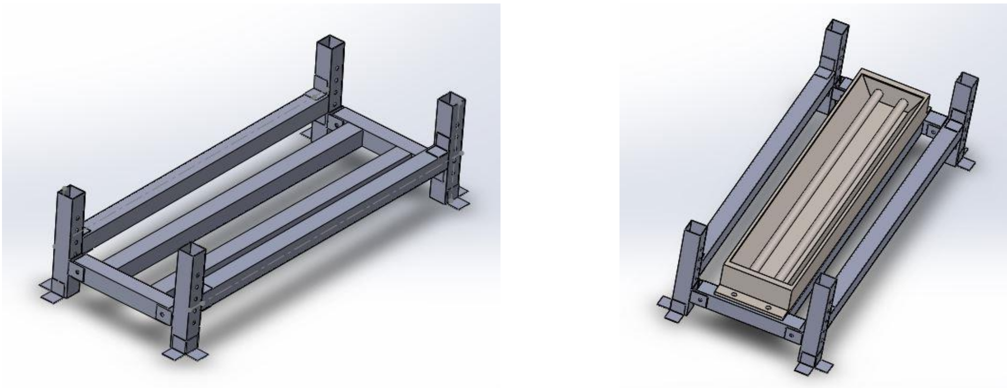

Figure 26: Design 1 for Infrared Mounting System

Design 2

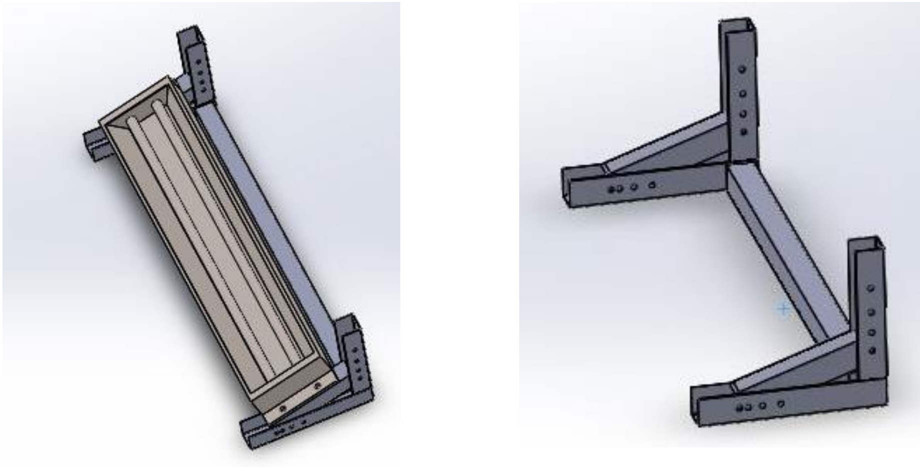

Figure 27: Design 2 for Infrared Mounting System

Our first iteration met our design parameters, however this design was very bulky and utilized more area than intended. After realizing our first had several flaws we created another iteration of the mounting system. Our second iteration used half the amount of material required for the first. Also, after comparing the two designs our team agreed adjusting the angle of the second iteration would be much easier. As a result the second iteration became the best design due to ability to adjust angles of the IR tubes and its size.

5.6 Task Specifications

Table 11: Task specifications for conveyor belt

Parameters	Dimensions	Category
Max length	Design must have length less than 208cm	Size
Payload	Conveyor belt system must be able to support 50kg without stalling	Functionality
Power	Design must be by one motor and drying unit must consist of four IR	Cost Effectiveness
Speed	Speed of conveyor belt must be no less than .15 m/s and no greater than .18 m/s	Functionality
Insulation	must prevent heat loss	Cost Effectiveness
Max Diameter	Design must have a width less than 110 cm	Functionality
Feasibility	Design must prevent from jamming the flow of the conveyor belt system	Desire of Costumer
Tensioner	Design must include tensioner to increase or decrease the tension of the belt	Functionality
Operational Cost	must cost less than $28,400 per year	Cost effectiveness
Operating Temperature	Must have greater than the boiling point of water but less than melting point of an aluminium can	Safety
Joints	Intersections between pieces of metal must welded	Functionality

Table 12: Task specifications: Infrared mounting system

Parameters	**Dimensions**	**Category**
Max volume	Max volume of the mounting system must be less than 29,250 cm^3	Size
Payload	Design must be to support the 10kg IR tube	Functionality
Adjustability	Mounting system must be able to change the angle from 35^0 to 0^0 increments in 10^0 increments	Functionality
Heat Resistant	Material used must have a melting higher than the operating temperature of the IR tubes	Functionality

6. Experiments and Results

6.1 Assumptions

Before doing our experiments, we made the following assumptions:

1. Heat is even throughout the system.
2. Ignore air dry affect.
3. Assume no water drops during experiments.
4. Every can is exactly the same.
5. All infrared tubes output the same power and release the same amount of heat all the time.
6. Assume energy cost is in direct proportion to the area of the working section.

6.2 Static Experiment

Our first experiment was a static test to see how long it takes to dry the cans when they are on top of the infrared tubes, similar to the last group. We will test how much they dry in 7 seconds and then in 46 seconds.

Static Experiment Tests

20 Small Cans 7 seconds 5 trials	**20 Small Cans 46 seconds 5 trials**
20 Big Cans 7 Seconds 5 trials	20 Big Cans 46 seconds 5 trials

Figure 28: Static Experiment Tests

The procedure for our experiment was:

1. Number each can 1 to 20
2. Weigh each dry can and record its mass
3. Spray all cans on the inside with water and on the outside as if it were going through the washing machine.
4. Pour out any excess water but be sure inside of cans are still wet
5. Weigh each can and record its mass
6. Calculate how much water is on each can
7. Turn on infrared tubes to heat up
8. Place cans in the enclosure for time wanted (either 7 seconds or 46 seconds)
9. Once the time is up, turn off the infrared tubes and take cans out
10. Weigh each can and record its mass
11. Calculate how much water is left
12. Calculate the percentage that it dried
13. Repeat this to get 5 trials for each test run

6.3 Static Results

After completing the four tests with 5 trials each, we were able to determine that the small cans dry on average 42.2% after 7 seconds in the enclosure and 90.5% after 46 seconds in the enclosure. The big cans dry on average 41.6% after 7 seconds in the enclosure and 88.6% after 46 seconds in the enclosure. (See Appendix A for full experimental data.)

These results have several indications. First, it shows that there is not a significant difference between the drying percentage of the big cans and small cans. Therefore, as we move forward with further tests, it is not necessary to test both types of cans. These results also give us the control value of about 42% drying percentage for the cans with the tubes being at 0 degrees. As we move forward and do experiments with the infrared tubes being at different angles, we can compare those results with this value, to see which angle is most drying efficient.

Table 13: Static Experiment Original Results

Size&Time	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
Small, 7s	33.649	49.186	40.019	44.816	43.266	42.187
Small, 46s	84.001	88.894	93.254	93.757	92.503	90.482
Big, 7s	35.173	46.97298	43.560	41.094	42.261	41.612
Big, 46s	88.191	88.334	89.600	88.492	88.331	88.590

Size&Time	Standard Deviation	Min	Max	New Average
Small, 7s	5.802	34.563	51.970	44.322
Small, 46s	4.093	86.364	98.643	92.102
Big, 7s	4.312	34.793	47.730	41.612
Big, 46s	0.575	87.472	89.196	88.337

Table 14: Static Experiment Standard Deviation

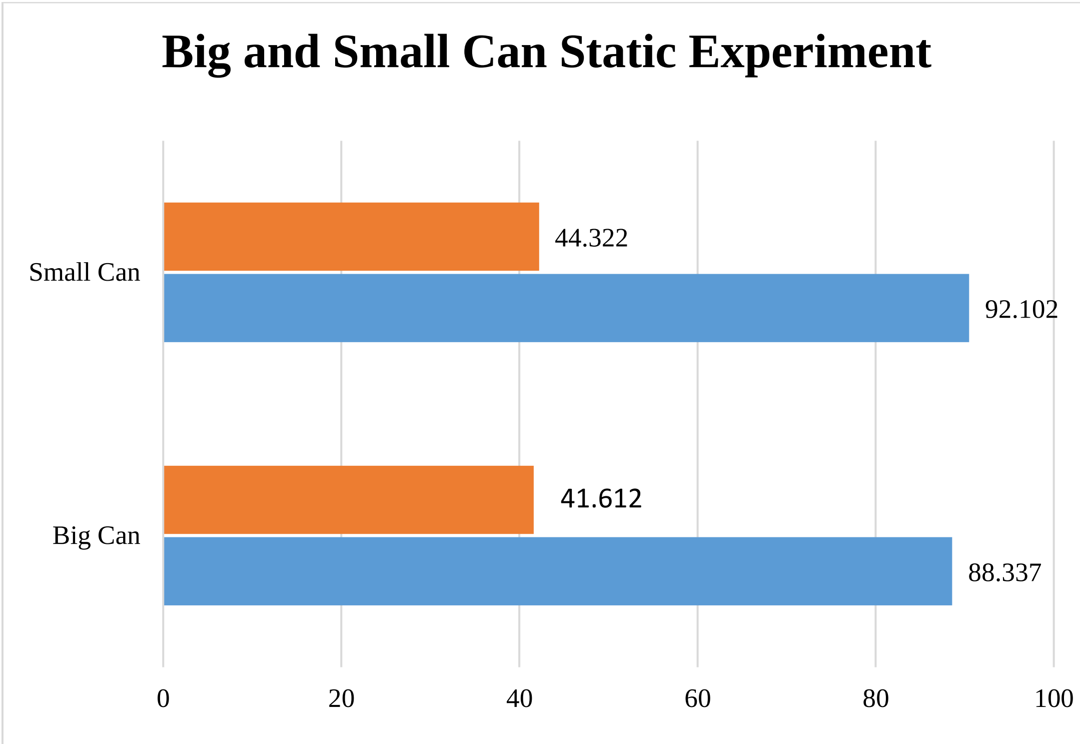

Figure 29: Static Experiment Results

6.4 Infrared Angle Experiment

The second set of experiments will be the angle tests. We set the infrared tubes in four different angles, 15, 22, 28, 35, to see how the drying percentage would change because of that. For all four tests, we used the small cans to be dried for 7 seconds and did 5 trails for each test.

The procedure for our experiment was:

1. Set angle for infrared tubes to 15 degrees
2. Number each can 1 to 20
3. Weigh each dry can and record its mass
4. Pour 5mL of water in a can and twirl can in counterclockwise direction to make sure the inside of the can gets wet
5. Pour out excess water to next can until all cans have the insides wet.

6. Weigh each can and record its mass
7. Calculate how much water is on each can
8. Turn on infrared tubes for 30 seconds to heat up
9. Place cans in the enclosure and start the timer
10. Once it is 7 seconds, turn off the infrared tubes and take cans out
11. Weigh each can and record its mass
12. Calculate how much water is left
13. Calculate the percentage that it dried
14. Set the angle to 22 degrees and repeat steps 2-13
15. Set the angle to 28 degrees and repeat steps 2-13
16. Set the angle to 35 degrees and repeat steps 2-13

6.5 Infrared Angle Results

Due to the results from the tests with four different angles, we were able to determine that the drying averages for 35, 28, 22, 15 are 58.340%, 50.523%, 44.642% and 40.979%. However, when we looked at the drying percentages for each trial, shown below in Table 15, some trials would the outliers in the sets of data.

Table 15: Angle Experiments Original Results

Angle	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
35	46.845	53.387	68.424	59.675	63.368	58.340
28	42.051	35.831	58.656	57.338	58.737	50.523
22	40.188	43.865	44.037	50.282	44.841	44.642
15	37.283	40.490	36.969	44.073	46.080	40.979

Therefore, we calculated the standard deviation and range for each angle test so that we were able to get a new and proper average for the drying percentage. All the calculation results are listed below in Table 16. (See Appendix B for more detailed data)

Table 16: Angle Experiments Standard Deviation

Angle	Standard Deviation	Min	Max	New Average
35	7.556	48.341	71.008	61.214
28	10.813	41.118	73.558	54.196
22	3.628	38.595	49.480	43.233
15	4.049	34.417	46.563	40.979

According to the new averages shown above and the result from static experiments, we were able to conclude that the infrared tubes with 35 degrees up from the ground level have the best working efficiency and drying percentage for the small cans, which is about 61.214% for 7 seconds.

6.6 Dynamic Experiment

The last set of experiments was the dynamic tests. We set the infrared tubes in the largest angle, 35 degrees, and put them into the new prototype with conveyer belt system to see how the drying percentage would change in the dynamic situation. We only did tests on the small cans for 5 trails. Also, the cans would be dried for 7 seconds through the entire oven.

The procedure for our experiment was:

1. Number each can 1 to 20
2. Weigh each dry can and record its mass

3. Pour 5mL of water in a can and twirl can in counterclockwise direction to make sure the inside of the can gets wet
4. Pour out excess water to next can until all cans have the insides wet.
5. Weigh each can and record its mass
6. Calculate how much water is on each can
7. Turn on infrared tubes for 30 seconds to heat up
8. Place cans in the enclosure and start the timer
9. Once it is 7 seconds, turn off the infrared tubes and take cans out
10. Weigh each can and record its mass
11. Calculate how much water is left
12. Calculate the percentage that it dried

6.7 Dynamic Experiment Results

Table 17, shown below, is the summary of the drying percentage for each trial and the overall. We got the drying percentage of 44.010% in this experiment, which is lower than the result from the angel tests. But the drying percentage for the dynamic tests is still good enough for 7 second. Also, like we did for previous experiments, we will still need to get rid of the outliner to have a new and precise average drying percentage for the dynamic tests.

Table 17: Dynamic Experiment Original Results

Angle	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Average
35	43.259	48.108	40.989	40.352	47.343	44.010

Figure 30: Dynamic Experiment

Therefore, we calculated the standard deviation and range for each angle test so that we could be able to get a new and proper average for the drying percentage. And all the calculation results are listed below in Table 18. (See Appendix C for more detailed data)

Table 18: Dynamic Experiment Standard Deviation

Angle	Standard Deviation	Min	Max	New Average
35	3.570	37.904	48.614	44.010

According to the table shown above, the 5 trial do not have any outliner, therefore, the average remains the same. The overall average of the drying percentage for the dynamic tests would be 44.010%, which is good enough for only 7 seconds.

6.8 Possible Errors in Experiments

There are several possible errors in this experiment. First, we used the old prototype from last year to redo the four experiments and compare the results for different sizes of the cans and time periods. The enclosure of the old prototype is made from a thin sheet of unstable stainless steel plate (see Figure 31). The two big open ends and the thin cover would cause a lot of heat loss from the system, which may have decreased the efficiency of the drying equipment. In our new prototype, we will try to fix this problem by placing cotton in between two aluminum plates. This should help store heat and prevent the drying process from losing heat.

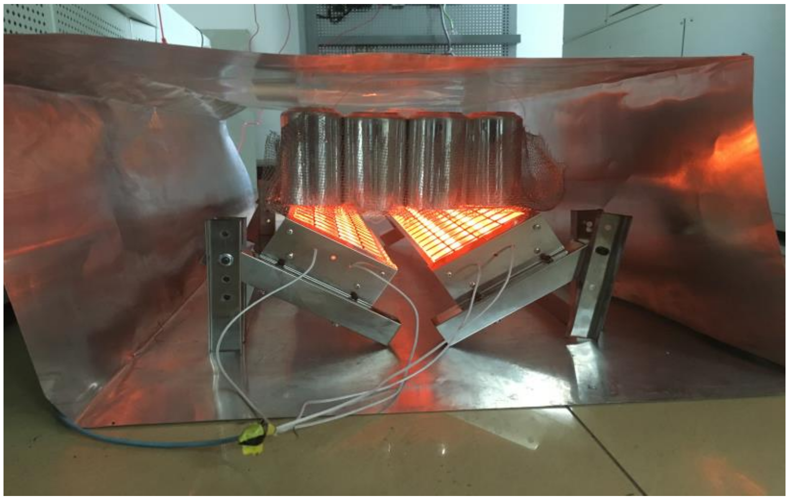

Figure 31: Angle Experiment in Enclosure

Another possible error was the difference in cans. When we tried to wet the cans during the experiments, we found out the cans were not all under the same condition. Shown in Figure 32, we could see there are a lot of drops of water sticking on the inner surface of the can. But

Figure 32: Can with Big Drops

shown in Figure 33, the can is wetted evenly and has a smooth inner surface. After drying both kinds of cans under the same condition, we found out that the cans with big drops were much harder to reach a perfectly dried state. According to what we saw on the production line, all cans will have smooth wet surface after the washing process, which means we should focus more on the results from the kind of cans shown in Figure 33. Therefore, having cans with big drops may decrease the drying percentage a lot.

Figure 33: Can with Smooth Surface

In addition, during the experiments, we used tap water to wet the can, which may be different from the washing solution used on the production line. We believe this might be a reason why some of the cans contain a lot of big drops on the inner surface.

The next possible error would be air drying time. During the experiment, it took us about half an hour to do one trial. We had to wet the cans several times to make sure all the cans were evenly wet, and we weighed the twenty cans one by one to collect all the necessary data. Those steps took a lot of time, which allow for air drying time. This air drying time could cause our drying percentage to be a bit higher than it actually is.

Last but not least, when we did the experiments, we could not find an appropriate and precise scale. Therefore, we decided to use a kitchen scale to weigh the cans, which only measure one digit after the decimal point. This made it difficult to get the most accurate data. Moving forward, we will borrow an old scale from chemistry department, which will measure three digits after the decimal point, so that our future experiments will have more accurate results.

7. Conclusion

Overall our team is very pleased with the outcomes of our project. We were able to successfully advance the previous MQP's project by creating a dynamic model of our solution and doing further tests to get more accurate data about our solution. The results from the experiments were positive showing that the Step 1 we came up with would dry the cans about 44% before entering the ovens which in turn means that the ovens will be used 44% less, which not only saves the company money from using less energy from the ovens, but is also more environmentally friendly.

We were also able to create a viable and functional dynamic prototype that mimicked the production line in order to get accurate results about the drying percentage that our Step 1 can dry the cans at.

All of our results show that this Step 1 is going in the right direction and will help the company reduce costs and be more energy efficient and environmentally friendly if implemented. This project has potential to move forward with another MQP group and actually get implemented onto the Pacific Can production line.

7.1 Recommendations and Future Work

7.1.1 Thermal Analysis

In order to improve the efficiency of this conveyer belt system, future teams should include 5-7 thermocouples within the insulation cover to determine if the radiation from the IR tubes is dissipated evenly throughout the system. Experiments conducted during this MQP proved that Aluminium cans did dry evenly, however using thermocouples would validate our results. Several types of thermocouples can be deemed suitable, these include K, J, N, and T type thermocouples. However due to constraints such as price future teams should use K-type thermocouple because it is relatively inexpensive, accurate, reliable and can withstand high levels of radiation. All-inclusive thermocouples and receiver units can be pricey, thus using a K-type thermocouple in combination with a Nano-Arduino and a Max6675 will reduce cost but still produce acceptable results.

7.1.2 Voltage regulator

Insulation incorporated into the current design reflects radiation back toward the cans on the conveyor belts, the interior surface of insulation layer was polished to improved reflection. As time passes the polish will deteriorate, therefore future teams should re-polish the interior. Also, if heat is dissipated evenly throughout the system and if temperature remains constant during an experiment, than future teams can add a voltage regulator to the IR tubes. The Voltage regulator would turn off the IR tubes when the temperature inside the insulation system when the temperature is high enough to dry can, but turn on IR tubes when the temperature falls below the necessary temperature to dry cans. Incorporating the this feature will reduce energy required for the system, this improving the return on investment

7.1.3 Testing cans

This year, we did not have enough cans to replace the cans with big drops. Like we mentioned in the experiment problem part, the cans after the washing section on the production line all have smooth surface inside and outside. Therefore, cans with big drops will cause a lot of errors on the result. It would be a good idea to test all cans before doing any kinds of experiments. Also, due to limitation of material, we used the tap water to wash all the cans during experiments. If it is possible, the next group would want to ask the company for the washing solution used on the production line or could get wet cans directly from the production line. This would be the ideal case for selecting cans and limiting all the possible error before doing the experiments.

7.1.4 Testing the prototype

Due to the lack of time, we were only able to do three sets of experiment. The next group would want to redo the static and angle tests with the new prototype so that they will be able to have more precise and comprehensive data for comparison and to prove that the infrared tube system works better on the production line. Also, in the angle test, we only test 4 different angles, which have a direct proportion to the drying percentage. The next group should test more angles, like 45 degrees, 50 degrees and 55 degrees, until the data show an obvious decrease on the drying percentage with the increased angle. By doing that, they could find a better working angle for the prototype. Last but not the least, because we did the first two sets of experiments on the old static prototype, we were not able to do tests with more cans. We only did 20 cans at a time. But with the conveyer belt system, the next group would be able to do experiments with more cans at a time. With more can being tested, the result would make more sense and be more precise.

7.1.5 Buying materials

We had a lot of problems with buying the materials. We would strongly recommend the next group to go and check the machine shop in Pacific Can first. Later, the group could talk to the engineers about their plan of improving the prototype. The engineers will always give a lot of valuable advice and provide a lot of useful materials the group would need. It will save money and time for the next group if they talk to the engineer and make a plan first.

7.1.6 Improving the prototype

In our design, we used 4 roller to drive the conveyer belt, but after testing the conveyer belt, we found out that the friction between the rollers and the conveyer belt is not enough to drive the entire system. To fix the problem, we added several robber type on the rollers to increase the friction. But for a better design, the next group could get one more roller and fix it in between the top roller and the low roller, which would force the conveyer belt to be in S shape. This design would have a better tighten conveyer belt and enable the roller to drive the conveyer belt more successfully by having more touching area between the roller and the conveyer belt. Due to the lack of time, we were not able to adjust the roller perfect in parallel. The next group would help adjust the conveyer belt when adding the roller into the prototype. When we built the prototype this time, we drilled holes for letting the pin go through. However, to do a better adjusting on the conveyer belt, drilling slots would make more sense. Also, for waterproof purpose, the next group could drill holes on the bottom of the infrared tube cases, therefore, the big water drops could easily go through without damage the infrared tubes. When testing the prototype, we found out that the result decrease a lot from doing the static test. We thought the major reason would be distance between the cans and the infrared tubes. We took a close look at the two different layers. There is still a lot of empty space between two layers, which would cause a serious heat loss problem during the experiment. We strongly recommend that the next group could fix this problem by lowing down the top layer or making the structure adjustable to height.

7.1.7 Improving insulation system

The primary purpose of the insulation is to contain the radiation from the IR tubes. The current insulation prevents heat loss however the perimeter of the insulation layer temperature is 125^0 C degrees while the interior of the insulation is 280^0 C while the temperature of the IR tubes is 325^0 C. Future MQP teams should investigate other insulation method/ improve upon the current insulation to minimalize heat loss further.

7.2 Constraints

Throughout this project, there were several constraints that made it difficult to achieve our goals and objectives.

The first constraint was the size of the space that Pacific Can allotted us to implement our drying system in. It was much smaller than what we expected, which caused the need for several changes in our design in order to fit in that space.

The second constraint was the lack of resources available to us. Once we arrived, it was difficult to find a lab space to conduct experiments with our infrared tubes without shortening the circuit in the lab. There was no machine shop available to us to create our oarts for the prototype, which resulted in us using the machine shop at Pacific Can. There was no location to pick up materials, so we had to order online which made it difficult to see if the material was what we wanted and if it would work with our design.

The third constraint was the language barrier. Although two of our team members spoke Chinese, it was difficult to explain to BUCT students in technical terms what we were planning to do and what we needed to accomplish our goals and objectives. The BUCT students were also busy with competitions and schoolwork so it was difficult to meet with them to go over progress of the project and get their help.

The last constraint was the Wi-Fi. The Wi-Fi would crash several times and take a long time to get back up and running which made it difficult to continue research about different methods we would think of using to accomplish our project.

8. References

1. "PLC Data Sheet." *Data Sheet*. Siemens, 26 Apr. 2015. Web. 17 Apr. 2016. <http://docs-europe.electrocomponents.com/webdocs/117f/0900766b8117fbf3.pdf>.
2. Mongpraneet, S., T. Abe, and T. Tsurusaki. "Accelerated Drying of Welsh Onion by Far Infrared Radiation under Vacuum Conditions." *Journal of Food Engineering* 228 Jan. 2002: 147-56. Print.
3. AK Yetisen, LR Volpatti, AF Coskun, S Cho, E Kamrani, H Butt, A Khademhosseini and SH Yun (2015)."Entrepreneurship".
4. "Entrepreneurship." Businessdictionary.com, 2014. Web. <http%3A%2F%2Fwww.businessdictionary.com%2Fdefinition%2Fentrepreneurship.html%23ixzz3xv9ci0nt>.
5. Maryville, S (1992). "Entrepreneurship in the Business Curriculum". *Journal of Education for Business*. Vol. 68 No. 1, pp. 27-31. <http://www.tandfonline.com/doi/abs/10.1080/08832323.1992.10117582>.
6. “Innovation | Definition of Innovation by Merriam-Webster". *Merriam-webster.com*. Retrieved 2016-03-14.
7. "Our Business." Pacific Can, n.d. Web. <http://www.pacificcan.com/en/>.
8. Sink, Justin. "Major US Corporations Pledge To Increase Renewable Energy Usage, Decrease Carbon Footprint In an Effort to." Renewable Energy World, 27 July 2015. Web. <http://www.renewableenergyworld.com/news/2015/07/major-us-corporations-pledge-to-increase-renewable-energy-usage-decrease-carbon-footprint.html>.

9. Woodward, Angela. "Aluminum Beverage Can." *How Aluminum Beverage Can Is Made*. N.P., 2016. Web. <http://www.madehow.com/Volume-2/Aluminum-Beverage-Can.html>.
10. "Alcoa RPD: About Alcoa Rigid Packaging: How Aluminum Cans Are Made." *About Alcoa Rigid Packaging: How Aluminum Cans Are Made*. Alcoa RPD, n.d. Web. <http://www.alcoa.com/rigid_packaging/en/info_page/making_cans.asp>.
11. "Ball: Who We Are Is in All We Do." *How Beverage Cans Are Made*... Ball, n.d. Web. <https://www.ball-europe.com/Production-process-of-beverage-cans.htm>.
12. "Making a Can." *Making a Can*. Rexnam PLC, n.d. Web. <http://www.rexam.com/index.asp?pageid=484>.
13. "Basic Information about Infrared (radiant) Heating," MOR Electric Heating, n.d. Web. <https://www.infraredheaters.com/basic.html>.
14. "High Temperature Conveyor Belt" MIPR Corporation, n.d. Web. <http://www.conveyor-belts-belting.com/conveyor-belts/high-temperature-conveyor-belts>.
15. "Methods of Heat Transfer," The Physics Classroom, n.d. Web. <http://www.physicsclassroom.com/class/thermalP/Lesson-1/Methods-of-Heat-Transfer>.
16. Mann, David. "A Conveyor Belt is Only as Good as the Belt That's on It." Bastian Solutions. N.p., 2016. Web. <https://www.bastiansolutions.com/blog/index.php/2013/12/12/conveyor-belt-types-and-applications/#.V68VA5grKhd>.
17. "Water Thermal Properties," The Engineering Toolbox, n.d. Web. <http://www.engineeringtoolbox.com/water-thermal-properties-d_162.html>.

18. "What is Infrared." *Infrared Astronomy*. Cool Cosmos. n.d. Web. <http://coolcosmos.ipac.caltech.edu/cosmic_classroom/ir_tutorial/what_is_ir.html>.
19. "Conveyor Belt- Installation, Maintenance & Troubleshooting Guide." *Continental- The Future in Motion*. Continental, n.d. Web. 30 June 2016.
20. "K-type Thermometer with LCD in Arduino Nano." Devacron, 27 Dec. 2013. Web. 17 July 2016.
21. "Return on Investment (ROI)." *Small Business Encyclopedia*. Entrepreneur, n.d. Web. 19 July 2016.
22. "Stress & Structural Analysis." *Dayton T. Brown*. Dayton T. Brown, n.d. Web. 15 July 2016.
23. "Thermocouples." *Omega*. Omega Engineering Inc., n.d. Web. 17 July 2016.
24. Watkins, Thayer. "An Introduction to Cost Benefit Analysis." *San Jose State University Department of Economics*. N.p., n.d. Web. 19 July 2016

Appendix

A. Static Experiment Data

Can #	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec
1	10.7	12.0	11.5	10.6	12.0	11.2	10.6	11.9	11.5	10.7	12.0	11.5	10.7	11.9	11.6
2	10.7	12.1	11.7	10.8	12.0	11.4	10.7	11.7	11.2	10.7	11.5	11.1	10.6	11.5	11.0
3	10.5	12.1	11.6	10.7	12.2	11.4	10.6	11.3	11.1	10.7	11.6	11.1	10.6	11.4	11.0
4	10.7	12.4	11.9	10.7	12.4	11.6	10.7	11.8	11.2	10.7	11.8	11.3	10.7	11.7	11.1
5	10.6	12.3	11.8	10.5	11.9	11.3	10.4	11.7	11.1	10.4	12.0	11.2	10.4	11.5	11.1
6	10.6	11.7	11.2	10.5	12.0	11.1	10.4	11.3	10.9	10.5	11.1	10.9	10.5	12.0	11.6
7	10.5	11.5	11.1	10.5	12.4	11.3	10.6	11.2	11.0	10.5	11.2	10.9	10.5	11.6	11.1
8	10.5	11.2	11.0	10.5	11.2	10.8	10.5	11.1	10.9	10.5	11.2	10.9	10.6	11.0	10.8
9	10.7	11.9	11.4	10.6	11.9	11.1	10.7	11.7	11.3	10.6	11.3	11.0	10.6	11.1	10.9
10	10.4	12.3	11.7	10.4	12.0	11.4	10.5	11.8	11.3	10.5	11.2	10.9	10.4	11.1	10.7
11	10.6	12.4	11.7	10.6	12.5	11.9	10.6	11.8	11.4	10.6	11.5	11.3	10.7	12.2	11.8
12	10.6	11.8	11.4	10.7	12.4	11.4	10.7	11.2	10.9	10.7	11.5	11.2	10.6	11.7	11.2
13	10.4	11.4	11.1	10.3	11.9	10.9	10.3	11.0	10.7	10.3	11.2	10.8	10.4	11.2	10.9
14	10.5	11.9	11.4	10.5	12.0	11.5	10.5	11.2	10.9	10.5	11.7	11.1	10.5	11.3	10.9
15	10.5	12.2	11.7	10.6	12.0	11.5	10.4	11.9	11.3	10.4	12.2	11.2	10.4	11.0	10.7
16	10.8	12.4	11.9	10.7	12.1	11.5	10.7	12.1	11.5	10.7	11.6	11.1	10.7	12.2	11.7
17	10.7	12.3	11.8	10.4	12.0	11.2	10.5	11.3	11.0	10.5	11.3	11.0	10.5	12.0	11.5
18	10.4	11.8	11.3	10.4	12.2	11.1	10.3	11.1	10.9	10.5	11.2	10.8	10.4	11.1	10.8
19	10.5	11.6	11.2	10.5	11.5	11.0	10.5	11.5	11.1	10.5	12.2	11.2	10.5	11.1	10.8
20	10.6	12.1	11.7	10.6	11.5	11.2	10.6	11.7	11.3	10.6	12.1	11.6	10.6	11.4	11.0

Figure 34: Small Cans Drying Percentage After 7 Seconds

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
38.46154	57.14286	30.76923	38.46154	25.00000	37.9670
28.57143	50.00000	50.00000	50.00000	55.55556	46.8254
31.25000	53.33333	28.57143	55.55556	50.00000	43.74206
29.41176	47.05882	54.54545	45.45455	60.00000	47.29412
29.41176	42.85714	46.15385	50.00000	36.36364	40.95728
45.45455	60.00000	44.44444	33.33333	26.66667	41.9798
40.00000	57.89474	33.33333	42.85714	45.45455	43.9080
28.57143	57.14286	33.33333	42.85714	50.00000	42.3810
41.66667	61.53846	40.00000	42.85714	40.00000	45.21245
31.57895	37.50000	38.46154	42.85714	57.14286	41.5081
38.88889	31.57895	33.33333	22.22222	26.66667	30.5380
33.33333	58.82353	60.000000	37.50000	45.45455	47.02228
30.00000	62.50000	42.85714	44.44444	37.50000	43.46032
35.71429	33.33333	42.85714	50.00000	50.00000	42.3810
29.41176	35.71429	40.00000	55.55556	50.00000	42.13632
31.25000	42.85714	42.85714	55.55556	33.33333	41.17063
31.25000	50.00000	37.50000	37.50000	33.33333	37.91667
35.71429	61.11111	25.00000	57.14286	42.85714	44.36508
36.36364	50.00000	40.00000	58.82353	50.00000	47.03743
26.66667	33.33333	36.36364	33.33333	50.00000	35.93939
33.64855	49.18599	40.01905	44.81555	43.26641	42.18711

Figure 35: Result of Small Cans After 7 Seconds

Can #	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec
1	10.7	12.7	11.3	10.7	11.8	10.9	10.7	12.1	10.9	10.6	11.9	10.7	10.7	12.4	10.8
2	10.7	12.2	11.0	10.7	11.5	10.7	10.6	11.8	10.6	10.6	11.3	10.7	10.7	11.7	10.7
3	10.6	11.4	10.6	10.6	11.1	10.6	10.6	11.4	10.6	10.5	11.4	10.5	10.6	11.3	10.6
4	10.8	11.5	10.9	10.7	11.5	10.8	10.7	11.2	10.7	10.6	11.2	10.6	10.6	11.4	10.7
5	10.5	11.5	10.5	10.4	11.3	10.6	10.4	11.2	10.4	10.4	11.1	10.4	10.4	11.4	10.4
6	10.6	12.5	11.1	10.5	12.1	10.8	10.5	12.4	10.8	10.5	11.7	10.5	10.4	12.7	10.7
7	10.5	11.9	10.9	10.5	11.9	10.8	10.5	11.5	10.5	10.4	11.6	10.4	10.4	11.7	10.5
8	10.5	11.2	10.7	10.5	11.0	10.6	10.4	11.0	10.4	10.6	11.6	10.6	10.5	11.3	10.6
9	10.6	11.3	10.8	10.5	11.1	10.5	10.6	11.1	10.6	10.6	11.3	10.7	10.6	11.6	10.6
10	10.4	11.0	10.5	10.4	11.2	10.4	10.5	11.0	10.5	10.5	11.1	10.5	10.4	12.7	10.6
11	10.6	12.8	11.1	10.6	12.4	10.9	10.7	12.2	11.0	10.6	11.8	10.7	10.7	12.5	10.7
12	10.6	12.4	11.1	10.7	12.1	10.8	10.6	11.7	10.8	10.7	11.6	10.7	10.6	12.1	10.6
13	10.4	11.0	10.5	10.4	11.1	10.4	10.4	10.9	10.4	10.5	11.1	10.5	10.4	11.1	10.4
14	10.6	11.3	10.7	10.6	11.1	10.6	10.5	11.0	10.5	10.5	11.1	10.6	10.5	11.4	10.5
15	10.5	11.2	10.5	10.4	11.1	10.5	10.4	11.1	10.4	10.4	11.0	10.5	10.5	12.1	10.8
16	10.7	12.3	10.9	10.7	11.9	10.9	10.7	12.2	11.0	10.7	12.3	11	10.8	12.7	11.1
17	10.6	11.9	10.6	10.5	11.4	10.7	10.5	11.5	10.6	10.5	11.6	10.7	10.5	11.6	10.7
18	10.5	11.0	10.5	10.3	10.9	10.4	10.4	10.9	10.4	10.4	11.0	10.4	10.4	11.3	10.5
19	10.5	11.2	10.6	10.5	11.2	10.5	10.5	11.1	10.6	10.5	11.1	10.5	10.5	11.5	10.6
20	10.6	12.2	10.9	10.6	11.9	10.8	10.5	12.0	10.8	10.6	11.6	10.7	10.8	12.7	11.1

Figure 36: Small Cans Drying Percentage After 46 Seconds

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
70.00000	81.81818	85.71429	92.30769	94.11765	84.79156
80.00000	100.0000	100.0000	85.71429	100.0000	93.14286
100.0000	100.0000	100.0000	100.0000	100.0000	100.0000
85.71429	87.50000	100.0000	100.0000	87.50000	92.14286
100.0000	77.77778	100.0000	100.0000	100.0000	95.55556
73.68421	81.25000	84.21053	100.0000	86.95652	85.22025
71.42857	78.57143	100.0000	100.0000	92.30769	88.46154
71.42857	80.00000	100.0000	100.0000	87.50000	87.78571
71.42857	100.0000	100.0000	85.71429	100.0000	91.42857
83.33333	100.0000	100.0000	100.0000	91.30435	94.92754
77.27273	83.33333	80.00000	91.66667	100.0000	86.45455
72.22222	92.85714	81.81818	100.0000	100.0000	89.37951
83.33333	100.0000	100.0000	100.0000	100.0000	96.66667
85.71429	100.0000	100.0000	83.33333	100.0000	93.80952
100.0000	85.71429	100.0000	83.33333	81.25000	90.05952
87.50000	83.33333	80.00000	81.25000	84.21053	83.25877
100.0000	77.77778	90.00000	81.81818	81.81818	86.28283
100.0000	83.33333	100.0000	100.0000	88.88889	94.44444
85.71429	100.0000	83.33333	100.0000	90.00000	91.80952
81.25000	84.61538	80.00000	90.00000	84.21053	84.01518
84.00122	88.8941	93.25382	93.75689	92.50322	90.48185

Figure 37: Result of Small Cans After 46 Seconds

Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec	Dry Can	Can w/water	After 7 sec
15.666	15.055	13.790	15.667	15.060	13.863	15.680	14.745	13.859	15.272	14.644	13.851	15.541	14.698
15.322	14.785	13.767	14.807	14.252	13.838	14.926	14.548	13.833	14.672	14.384	13.824	15.047	14.674
16.057	15.237	13.772	14.724	14.214	13.839	14.726	14.364	13.835	14.657	14.297	13.828	14.671	14.342
16.119	15.213	13.901	14.814	14.361	13.956	14.792	14.461	13.953	14.827	14.494	13.943	14.821	14.498
15.042	14.508	13.819	15.021	14.343	13.853	14.834	14.417	13.851	14.727	14.376	13.845	15.090	14.651
15.241	14.745	13.740	14.450	14.152	13.771	15.033	14.526	13.768	14.659	14.298	13.762	15.100	14.561
15.342	14.845	13.924	14.541	14.264	13.954	14.366	14.165	13.949	14.631	14.377	13.938	14.709	14.368
15.504	14.864	13.851	14.503	14.175	13.868	14.573	14.282	13.862	14.577	14.255	13.849	14.458	14.265
15.301	14.897	13.854	14.525	14.226	13.875	14.557	14.282	13.871	14.576	14.305	13.856	14.603	14.258
15.658	15.122	13.932	14.540	14.335	13.946	15.493	14.987	13.942	15.018	14.502	13.934	14.823	14.387
15.072	14.678	13.859	14.918	14.526	13.869	15.750	14.993	13.867	14.820	14.505	13.864	15.598	14.725
15.627	15.025	13.942	14.518	14.254	13.957	14.683	14.391	13.951	14.440	14.268	13.946	14.646	14.354
15.427	14.911	13.945	14.483	14.231	13.962	14.677	14.282	13.959	14.578	14.283	13.947	14.463	14.253
15.107	14.741	13.871	14.444	14.254	13.887	14.557	14.243	13.882	14.553	14.2361	13.876	14.478	14.218
15.208	14.663	13.854	14.421	14.123	13.862	15.097	14.578	13.861	14.574	14.263	13.856	14.721	14.352
15.210	14.745	13.828	14.310	14.067	13.834	14.796	14.311	13.833	14.670	14.388	13.830	14.733	14.306
15.026	14.654	13.930	14.554	14.198	13.938	14.722	14.362	13.935	14.637	14.298	13.933	14.554	14.316
15.179	14.775	13.841	14.391	14.162	13.848	14.843	14.369	13.847	14.589	14.284	13.846	14.572	14.315
15.182	14.737	13.843	14.482	14.109	13.848	14.960	14.444	13.848	14.704	14.377	13.844	14.596	14.347
14.710	14.366	13.743	14.472	14.065	13.747	15.175	14.549	13.745	14.892	14.388	13.746	14.762	14.258

Figure 38: Big Cans Drying Percentage After 7 Seconds

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
33.92560	32.33884	51.45845	44.44444	49.88166	42.40980
36.23482	53.36538	34.74265	34.32658	30.49877	37.83364
36.98692	53.57143	40.81172	43.79562	39.02728	42.83860
41.88627	49.61665	39.59330	38.10069	36.78815	41.19701
44.91169	56.40599	42.50765	40.06849	35.26104	43.83097
33.67278	41.97183	40.17433	40.51627	40.28401	39.32384
35.72969	44.89465	48.78641	37.24340	44.22827	42.17649
39.11980	50.30675	41.27660	45.03497	31.69130	41.48588
28.27152	44.56036	40.32258	38.43972	46.18474	39.55578
31.27188	33.71711	32.70847	47.95539	49.04387	38.93934
32.69710	37.01605	40.24455	33.05352	50.34602	38.67145
35.98326	45.83333	40.22039	35.17382	41.71429	39.78502
35.14986	46.84015	55.24476	47.65751	40.69767	45.11799
29.92641	33.15881	46.86567	47.22802	43.18937	40.07366
40.43027	52.55732	42.02429	43.61851	42.65896	44.25787
33.74456	50.41494	50.41580	33.69176	47.28682	43.11077
34.12844	57.05128	45.91837	48.29060	38.32528	44.74279
30.35312	41.63636	47.63819	41.10512	35.39945	39.22645
33.35832	58.37246	46.40288	38.20093	33.11170	41.88926
35.68465	55.82990	43.83754	43.94071	49.60630	45.77982
35.17335	46.97298	43.55973	41.09430	41.26125	41.61232

Figure 39: Result of Big Cans After 7 Seconds

Can #	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec	Dry Can	Can w/water	After 46 sec
1	13.838	14.976	13.995	13.858	14.953	13.925	13.850	15.213	13.947	13.860	15.448	13.950	13.860	14.930	13.981
2	13.788	14.686	13.864	13.831	14.951	13.998	13.822	14.829	13.938	13.834	14.743	13.928	13.833	14.938	13.921
3	13.790	14.586	13.847	13.838	14.745	13.988	13.824	14.778	13.915	13.826	14.683	13.974	13.834	14.780	13.956
4	13.900	14.738	13.963	13.949	14.852	14.092	13.942	14.956	14.041	13.867	14.655	13.975	13.952	14.863	14.082
5	13.822	14.745	13.946	13.850	15.220	14.002	13.843	14.979	13.983	13.842	14.735	13.929	13.854	14.692	13.976
6	13.741	14.571	13.868	13.766	14.600	13.845	13.759	14.867	13.877	13.764	14.736	13.826	13.768	14.571	13.878
7	13.919	14.466	14.015	13.946	14.546	14.027	13.935	14.833	14.018	13.935	14.743	13.985	13.948	14.811	14.082
8	13.737	14.372	13.821	13.860	14.513	13.890	13.847	14.678	13.962	13.844	14.677	13.958	13.863	14.650	13.901
9	13.838	14.492	13.871	13.867	14.664	13.987	13.860	14.801	13.959	13.856	14.551	13.966	13.871	14.689	13.921
10	13.927	14.402	13.965	13.939	15.354	14.176	13.938	14.807	14.057	13.937	15.321	14.021	13.945	15.794	14.155
11	13.852	14.857	13.954	13.863	15.038	13.955	13.861	15.102	13.987	13.862	15.013	13.984	13.866	14.730	13.951
12	13.933	14.520	14.021	13.950	14.716	13.993	13.943	14.824	13.984	13.941	14.627	14.055	13.954	14.688	14.028
13	13.932	14.476	13.998	13.956	14.563	14.015	13.949	14.642	14.015	13.952	14.733	14.054	13.960	14.630	14.092
14	13.863	14.392	13.929	13.881	14.617	13.970	13.877	14.755	13.978	13.878	14.596	13.985	13.884	14.699	13.963
15	13.854	15.349	13.987	13.858	15.641	14.179	13.857	14.745	13.963	13.859	14.655	13.969	13.862	15.480	14.015
16	13.824	14.463	13.902	13.831	14.774	13.863	13.831	14.508	13.925	13.833	15.064	13.936	13.834	14.783	13.952
17	13.925	14.467	14.023	13.931	14.596	13.982	13.930	14.701	13.985	13.934	14.667	13.992	13.937	14.884	13.987
18	13.838	14.434	13.932	13.847	14.496	13.965	13.847	14.816	13.981	13.847	14.688	13.968	13.849	14.653	13.964
19	13.841	14.496	13.865	13.846	14.792	13.966	13.846	14.804	13.928	13.844	14.731	13.924	13.848	14.695	13.976
20	13.743	14.393	13.862	13.746	14.791	13.895	13.746	14.698	13.828	13.747	15.042	13.962	13.747	14.950	13.927

Figure 40: Big Cans Drying Percentage After 46 Seconds

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
86.20387	93.88128	92.88335	94.33249	88.69159	91.19851
91.53675	85.08929	88.48064	89.65897	92.03620	89.36037
92.83920	83.46196	90.46122	82.73046	87.10359	87.31928
92.48210	84.16390	90.23669	86.29442	85.72997	87.78141
86.56555	88.90511	87.67606	90.25756	85.44153	87.76916
84.69880	90.52758	89.35018	93.62140	86.30137	88.89986
82.44973	86.50000	90.75724	93.81188	84.47277	87.59832
86.77165	95.40582	86.16125	86.31453	95.17154	89.96496
94.95413	84.94354	89.47928	84.17266	93.88753	89.48743
92.00000	83.25088	86.30610	93.93064	88.64251	88.82603
89.85075	92.17021	89.84690	89.40052	90.16204	90.28608
85.00852	94.38642	95.34620	83.38192	89.91826	89.60826
87.86765	90.28007	90.47619	86.93982	80.29851	87.17245
87.52363	87.90761	88.49658	85.09749	90.30675	87.86641
91.10368	81.99663	88.06306	86.18090	90.54388	87.57763
87.79343	96.60657	86.11521	91.63282	87.56586	89.94278
81.91882	92.33083	92.86641	92.08731	94.72017	90.78471
84.22819	81.81818	86.17131	85.61237	85.69652	84.70531
96.33588	87.31501	91.44050	90.98083	84.88784	90.19201
81.69231	85.74163	91.38655	83.39768	85.03741	85.45112
88.19123	88.33413	89.60005	88.49183	88.33079	88.58961

Figure 41: Result of Big Cans After 46 Seconds

B. Angle Experiment Data

35 Degrees															
Can #	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec
1	10.657	12.229	11.598	10.637	12.100	11.261	10.648	11.873	10.978	10.710	12.161	11.105	10.687	12.129	11.234
2	10.672	11.692	11.268	10.650	11.554	10.981	10.657	11.348	10.953	10.662	11.559	11.098	10.662	11.815	11.037
3	10.554	11.740	11.250	10.535	11.430	10.804	10.544	11.529	10.800	10.541	11.398	10.827	10.542	11.674	10.832
4	10.672	11.365	11.009	10.656	11.515	10.922	10.663	11.517	10.796	10.658	11.537	10.948	10.653	11.745	10.965
5	10.383	11.427	10.995	10.372	11.898	11.134	10.377	11.587	10.898	10.373	11.604	10.879	10.394	11.959	11.152
6	10.486	11.586	11.132	10.472	11.832	11.131	10.477	11.737	10.956	10.613	11.674	11.121	10.605	12.285	11.215
7	10.481	11.322	10.985	10.464	11.370	10.914	10.469	11.646	10.912	10.628	11.714	11.290	10.504	11.973	11.192
8	10.492	11.344	10.996	10.476	11.812	10.797	10.481	11.351	10.754	10.476	11.541	10.808	10.487	11.654	10.869
9	10.579	11.472	11.084	10.562	11.293	10.998	10.569	11.489	10.959	10.562	11.742	11.086	10.571	11.764	10.925
10	10.403	12.354	11.316	10.394	11.752	11.146	10.439	11.791	10.956	10.387	11.575	10.853	10.397	11.661	10.889
11	10.646	12.444	11.674	10.637	12.131	11.512	10.642	11.802	10.878	10.693	12.014	11.189	10.745	12.078	11.271
12	10.657	11.735	11.272	10.645	11.602	11.170	10.649	11.698	10.998	10.671	11.758	11.201	10.729	12.185	11.148
13	10.382	11.015	10.722	10.372	11.185	10.680	10.372	11.153	10.633	10.362	11.475	10.748	10.385	11.576	10.793
14	10.499	11.316	10.729	10.491	11.187	10.883	10.491	11.380	10.794	10.479	11.568	10.801	10.495	11.643	10.911
15	10.404	12.357	10.988	10.398	11.258	10.897	10.401	11.372	10.662	10.385	11.772	10.909	10.401	11.619	10.931
16	10.685	12.151	11.561	10.680	11.896	11.219	10.680	11.495	10.955	10.670	11.704	11.227	10.678	11.833	11.195
17	10.489	11.872	11.201	10.484	11.065	10.656	10.485	11.362	10.781	10.471	11.702	10.859	10.481	11.671	10.865
18	10.398	11.653	11.106	10.396	11.676	11.102	10.394	11.472	10.707	10.383	11.817	11.089	10.395	11.760	10.951
19	10.480	11.964	11.203	10.473	11.633	11.167	10.475	11.573	10.783	10.459	11.680	10.975	10.474	11.744	10.975
20	10.592	12.140	11.449	10.588	11.439	11.016	10.588	11.601	10.759	10.573	11.755	10.979	10.586	11.841	11.033

Figure 42: 35 Degrees Data

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
40.140	57.348	73.061	72.777	62.067	61.079
41.569	63.385	57.164	51.394	67.476	56.197
41.315	69.944	74.010	66.628	74.382	65.256
51.371	69.034	84.426	67.008	71.429	68.653
41.379	50.066	56.942	58.895	51.565	51.770
41.273	51.544	61.984	52.121	63.690	54.122
40.071	50.331	62.362	39.042	53.165	48.994
40.845	75.973	68.621	68.826	67.266	64.306
43.449	40.356	57.609	55.593	70.327	53.467
53.203	44.624	61.760	60.774	61.076	56.288
42.825	41.432	79.655	62.453	60.540	57.381
42.950	45.141	66.730	51.242	71.223	55.457
46.288	62.116	66.581	65.319	65.743	61.209
71.848	43.678	65.917	70.432	63.763	63.128
70.097	41.977	73.120	62.221	56.486	60.780
40.246	55.674	66.258	46.132	55.238	52.709
48.518	70.396	66.249	68.481	67.731	64.275
43.586	44.844	70.965	50.767	59.267	53.886
51.280	40.172	71.949	57.740	60.551	56.338
44.638	49.706	83.119	65.651	64.382	61.500
46.845	53.387	68.424	59.675	63.368	58.340

Figure 43: 35 Degrees Results

28 Degrees															
Can #	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec
1	10.678	12.293	11.752	10.668	11.715	11.341	10.642	11.597	11.165	10.657	12.080	11.279	10.656	12.045	11.149
2	10.690	11.760	11.192	10.654	11.579	11.212	10.650	11.622	10.985	10.671	11.644	10.972	10.663	11.652	10.956
3	10.543	11.419	10.909	10.533	11.497	10.994	10.537	11.508	10.757	10.546	11.469	10.877	10.544	11.645	10.740
4	10.662	11.496	11.075	10.659	11.761	11.235	10.661	11.762	11.089	10.668	11.617	11.042	10.658	11.678	10.944
5	10.607	11.423	11.019	10.375	11.783	11.501	10.469	11.788	11.107	10.382	11.409	10.974	10.377	11.601	10.952
6	10.538	11.764	11.511	10.508	11.484	11.201	10.473	11.469	10.986	10.484	11.653	11.202	10.477	12.007	11.255
7	10.566	12.119	11.601	10.574	11.951	11.640	10.509	11.885	11.144	10.483	11.655	10.985	10.471	11.628	11.046
8	10.526	11.520	11.012	10.476	11.401	11.131	10.476	11.541	10.931	10.489	11.530	10.817	10.477	11.479	11.101
9	10.651	11.501	11.188	10.572	11.692	11.432	10.634	11.739	11.109	10.576	11.759	11.044	10.564	11.744	11.144
10	10.386	11.426	11.183	10.437	11.701	11.532	10.517	11.615	11.099	10.403	11.695	11.198	10.394	11.794	11.295
11	10.621	12.143	11.735	10.762	11.839	11.504	10.653	11.622	11.154	10.647	11.666	11.133	10.635	11.828	11.025
12	10.647	12.145	11.553	10.799	12.060	11.587	10.661	11.995	11.159	10.655	11.753	11.217	10.643	12.057	11.091
13	10.379	11.362	10.972	10.361	11.403	11.026	10.372	11.387	10.773	10.379	11.392	10.733	10.369	11.558	10.727
14	10.495	11.341	10.887	10.479	11.634	11.072	10.491	11.406	10.936	10.496	11.551	10.914	10.488	11.543	10.994
15	10.402	11.478	11.032	10.386	11.692	11.301	10.534	11.611	11.085	10.403	11.373	10.952	10.394	11.699	11.079
16	10.627	11.892	11.431	10.665	11.625	11.153	10.678	11.528	10.906	10.683	11.408	10.886	10.669	11.912	10.936
17	10.547	11.613	11.131	10.471	11.510	10.999	10.483	11.624	10.857	10.486	11.430	10.706	10.476	11.551	10.915
18	10.442	11.824	11.116	10.381	11.791	11.142	10.393	11.438	10.737	10.396	11.413	10.721	10.387	11.611	10.855
19	10.496	11.586	10.977	10.459	11.626	11.126	10.477	11.633	10.919	10.475	11.583	10.922	10.469	11.569	10.962
20	10.611	11.782	11.301	10.604	12.183	11.657	10.737	11.883	11.107	10.591	12.021	11.380	10.581	12.063	11.332

Figure 44: 28 Degrees Data

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
33.498	35.721	45.236	56.290	64.507	47.050
53.084	39.676	65.535	69.065	70.374	59.547
58.219	52.178	77.343	64.139	82.198	66.815
50.480	47.731	61.126	60.590	71.961	58.378
49.510	20.028	51.630	42.356	53.023	43.309
20.636	28.996	48.494	38.580	49.150	37.171
33.355	22.585	53.852	57.167	50.303	43.452
51.107	29.189	57.277	68.492	37.725	48.758
36.824	23.214	57.014	60.440	50.847	45.668
23.365	13.370	46.995	38.467	35.643	31.568
26.807	31.105	48.297	52.306	67.309	45.165
39.519	37.510	62.669	48.816	68.317	51.366
39.674	36.180	60.493	65.054	69.891	54.258
53.664	48.658	51.366	60.379	52.038	53.221
41.450	29.939	48.839	43.402	47.510	42.228
36.443	49.167	73.176	72.000	78.520	61.861
45.216	49.182	67.222	76.695	59.163	59.495
51.230	46.028	67.081	68.043	61.765	58.830
55.872	42.845	61.765	59.657	55.182	55.064
41.076	33.312	67.714	44.825	49.325	47.250
42.051	35.831	58.656	57.338	58.737	50.523

Figure 45: 28 Degrees Results

22 Degrees															
Can #	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec
1	10.659	12.279	11.765	10.656	12.133	11.729	10.666	12.259	11.814	10.656	12.231	11.737	10.656	12.233	11.603
2	10.671	11.764	11.283	10.663	11.657	11.124	10.662	11.656	11.146	10.673	11.684	11.062	10.664	11.563	10.966
3	10.555	11.613	10.877	10.538	11.301	10.732	10.547	11.441	10.866	10.546	11.483	10.802	10.545	11.398	10.791
4	10.673	11.584	11.057	10.655	11.424	10.901	10.668	11.534	10.978	10.666	11.662	10.961	10.664	11.775	11.171
5	10.386	11.281	10.893	10.411	11.151	10.686	10.381	11.618	10.993	10.406	11.501	10.889	10.383	11.456	10.956
6	10.487	12.000	11.735	10.566	12.001	11.761	10.585	12.223	11.981	10.568	12.093	11.801	10.545	12.112	11.737
7	10.484	11.619	11.234	10.677	11.641	11.233	10.479	11.715	11.333	10.572	11.754	11.419	10.474	11.999	11.585
8	10.496	11.359	11.072	10.591	11.338	10.997	10.486	11.453	11.044	10.561	11.477	10.969	10.486	11.488	11.130
9	10.578	11.546	11.161	10.704	11.459	11.032	10.574	11.561	11.115	10.679	11.581	11.122	10.569	11.581	11.251
10	10.404	11.470	11.217	10.525	11.354	11.095	10.402	11.708	11.417	10.479	11.788	11.285	10.401	11.681	11.439
11	10.650	11.821	11.515	10.706	12.003	11.729	10.692	12.115	11.909	10.748	12.182	11.901	10.743	12.180	11.805
12	10.659	11.831	11.341	10.693	11.561	11.370	10.754	11.988	11.519	10.764	11.899	11.581	10.761	11.988	11.639
13	10.383	11.233	10.922	10.373	11.231	10.901	10.387	11.469	10.931	10.381	11.311	10.885	10.378	11.493	10.978
14	10.501	11.238	10.975	10.492	11.315	11.009	10.518	11.394	10.979	10.492	11.667	11.125	10.535	11.507	11.055
15	10.404	11.312	11.059	10.464	11.187	10.915	10.496	11.713	11.149	10.459	11.684	11.179	10.502	11.628	11.078
16	10.685	11.647	11.242	10.675	11.541	11.099	10.683	11.476	11.128	10.684	11.569	10.985	10.682	11.766	11.142
17	10.490	11.397	10.979	10.482	11.296	10.868	10.483	11.425	10.918	10.489	11.548	10.833	10.486	11.663	10.971
18	10.400	11.318	10.811	10.395	11.173	10.766	10.396	11.191	10.712	10.393	11.527	10.684	10.396	11.567	10.869
19	10.481	11.385	10.875	10.477	11.372	10.916	10.476	11.368	10.812	10.478	11.482	10.758	10.468	11.477	10.895
20	10.591	11.551	11.156	10.592	11.577	11.231	10.585	11.837	11.201	10.622	11.681	11.037	10.591	11.792	11.188

Figure 46: 22 Degrees Data

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
31.728	27.353	27.935	31.365	39.949	31.666
44.007	53.622	51.308	61.523	66.407	55.373
69.565	74.574	64.318	72.679	71.161	70.459
57.849	68.010	64.203	70.382	54.365	62.962
43.352	62.838	50.525	55.890	46.598	51.841
17.515	16.725	14.774	19.148	23.931	18.418
33.921	42.324	30.906	28.342	27.148	32.528
33.256	45.649	42.296	55.459	35.729	42.478
39.773	56.556	45.187	50.887	32.609	45.002
23.734	31.242	22.282	38.426	18.906	26.918
26.132	21.126	14.476	19.596	26.096	21.485
41.809	22.005	38.006	28.018	28.443	31.656
36.588	38.462	49.723	45.806	46.188	43.353
35.685	37.181	47.374	46.128	46.502	42.574
27.863	37.621	46.343	41.224	48.845	40.380
42.100	51.039	43.884	65.989	57.565	52.115
46.086	52.580	53.822	67.517	58.794	55.760
55.229	52.314	60.252	74.339	59.607	60.348
56.416	50.950	62.332	72.112	57.681	59.898
41.146	35.127	50.799	60.812	50.291	47.635
40.188	43.865	44.037	50.282	44.841	44.642

Figure 47: 22 Degrees Results

15 Degrees															
Can #	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec	Dry Can	Can w/wa	After 7 sec
1	10.696	12.022	11.621	10.651	12.347	11.935	10.700	12.404	11.961	10.635	12.389	11.947	10.641	12.371	11.926
2	10.675	11.652	11.241	10.657	11.808	11.190	10.662	11.762	11.244	10.643	11.816	11.140	10.644	11.892	11.144
3	10.554	11.541	11.048	10.537	11.606	10.935	10.539	11.636	11.011	10.522	11.656	10.975	10.529	11.494	10.876
4	10.671	11.861	11.325	10.655	11.639	11.114	10.658	11.719	11.148	10.649	11.851	11.179	10.646	11.613	10.950
5	10.382	11.512	11.036	10.370	11.372	10.752	10.375	11.609	10.895	10.362	11.486	10.831	10.361	11.389	10.770
6	10.626	12.101	11.910	10.515	12.261	11.973	10.541	12.246	11.926	10.545	12.387	11.982	10.566	12.438	12.108
7	10.617	11.904	11.666	10.632	12.168	11.817	10.704	12.212	11.859	10.464	12.181	11.723	10.489	12.244	11.787
8	10.590	11.691	11.222	10.485	11.652	11.273	10.491	11.788	11.339	10.465	11.783	11.353	10.472	11.728	11.208
9	10.674	11.845	11.245	10.569	11.906	11.551	10.629	11.893	11.296	10.555	11.898	11.318	10.558	11.795	11.208
10	10.465	12.002	11.687	10.425	11.989	11.726	10.557	12.186	11.702	10.393	11.842	11.489	10.386	12.059	11.609
11	10.772	12.333	11.923	10.726	11.961	11.779	10.707	12.491	11.999	10.703	12.721	12.195	10.695	12.356	11.940
12	10.739	12.114	11.831	10.748	12.152	11.851	10.648	12.391	11.994	10.655	12.440	11.948	10.664	12.418	12.002
13	10.396	11.486	11.019	10.496	11.573	10.991	10.371	11.615	11.224	10.363	11.816	11.001	10.365	11.519	10.998
14	10.502	11.488	11.166	10.604	11.746	11.251	10.485	11.745	11.466	10.479	11.725	11.143	10.482	11.945	11.256
15	10.413	11.671	11.283	10.651	11.637	11.301	10.401	11.731	11.396	10.391	11.744	11.121	10.395	11.671	10.948
16	10.685	11.721	11.255	10.680	11.735	11.284	10.673	11.824	11.481	10.676	12.098	11.416	10.672	12.014	11.424
17	10.491	11.458	11.031	10.484	11.469	10.961	10.485	11.594	11.176	10.482	11.899	11.179	10.476	11.732	11.034
18	10.401	11.377	10.855	10.393	11.315	10.712	10.392	11.556	11.013	10.388	11.711	10.952	10.389	11.732	10.836
19	10.481	11.509	10.997	10.471	11.501	10.909	10.473	11.831	11.158	10.466	11.831	11.029	10.470	11.874	10.998
20	10.594	11.865	11.295	10.591	11.898	11.195	10.591	11.869	11.216	10.581	12.071	11.204	10.583	12.153	11.252

Figure 48: 15 Degrees Data

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
30.241	24.292	25.998	25.200	25.723	26.291
42.068	53.692	47.091	57.630	59.936	52.083
49.949	62.769	56.974	60.053	64.041	58.757
45.042	53.354	53.817	55.907	68.563	55.336
42.124	61.876	57.861	58.274	60.214	56.070
12.949	16.495	18.768	21.987	17.628	17.566
18.493	22.852	23.408	26.674	26.040	23.493
42.598	32.476	34.618	32.625	41.401	36.744
51.238	26.552	47.231	43.187	47.454	43.132
20.494	16.816	29.711	24.362	26.898	23.656
26.265	14.737	27.578	26.065	25.045	23.938
20.582	21.439	22.777	27.563	23.717	23.216
42.844	54.039	31.431	56.091	45.147	45.910
32.657	43.345	22.143	46.709	47.095	38.390
30.843	34.077	25.188	46.046	56.661	38.563
44.981	42.749	29.800	47.961	43.964	41.891
44.157	51.574	37.692	50.812	55.573	47.961
53.484	65.401	46.649	57.370	66.716	57.924
49.805	57.476	49.558	58.755	62.393	55.597
44.847	53.787	51.095	58.188	57.389	53.061
37.283	40.490	36.969	44.073	46.080	40.979

Figure 49: 15 Degrees Results

C. Dynamic Experiment Data

35 degrees angle															
Can #	Dry Can	Can w/wa	After 7 se	Dry Can	Can w/wa	After 7 se	Dry Can	Can w/wa	After 7 se	Dry Can	Can w/wa	After 7 se	Dry Can	Can w/wat	After 7 se
1	10.654	12.392	11.787	10.900	12.449	11.745	10.653	12.151	11.756	10.715	12.409	11.998	10.630	12.485	11.645
2	10.667	11.809	11.200	10.660	11.414	11.036	10.665	11.958	11.640	10.673	12.223	11.871	10.646	12.148	11.512
3	10.545	11.266	10.847	10.545	11.145	10.782	10.547	11.559	11.210	10.556	11.613	11.397	10.535	11.904	11.312
4	10.664	11.412	11.075	10.669	11.246	11.010	10.670	11.417	11.012	10.674	11.466	11.165	10.664	11.653	11.013
5	10.374	11.329	10.845	10.381	11.139	10.802	10.383	11.358	10.812	10.385	11.467	11.015	10.382	11.330	10.947
6	10.482	12.153	11.852	10.937	12.065	11.876	10.478	11.988	11.579	10.514	12.105	11.647	10.475	12.402	11.981
7	10.470	12.015	11.168	10.485	11.718	11.013	10.479	11.717	11.041	10.486	12.162	11.471	10.169	12.211	11.381
8	10.491	11.786	11.141	10.490	11.357	10.998	10.492	11.478	11.019	10.495	11.654	11.187	10.480	11.881	11.130
9	10.567	11.328	10.998	10.582	11.266	10.991	10.580	11.392	11.016	10.593	11.550	11.086	10.575	11.864	11.056
10	10.400	11.772	11.218	10.415	11.682	11.102	10.408	11.562	11.121	10.409	11.871	11.089	10.404	11.869	11.134
11	10.639	12.097	11.645	10.909	11.865	11.457	10.650	12.131	11.516	10.701	12.359	11.745	10.643	12.551	11.715
12	10.664	12.484	11.846	10.761	11.921	11.402	10.660	11.972	11.263	10.664	12.359	11.778	10.729	12.497	11.764
13	10.382	11.185	10.845	10.381	11.028	10.601	10.381	11.119	10.792	10.386	11.415	10.987	10.377	11.817	11.201
14	10.505	11.220	11.000	10.499	11.075	10.831	10.502	11.318	10.998	10.501	11.461	11.016	10.499	11.619	11.022
15	10.392	11.083	10.737	10.407	11.099	10.814	10.407	11.814	10.906	10.415	11.168	10.781	10.406	11.618	11.071
16	10.674	11.562	11.096	10.692	11.293	10.989	10.685	11.253	11.023	10.687	11.831	11.321	10.675	12.185	11.351
17	10.484	11.267	11.011	10.493	11.091	10.737	10.490	11.050	10.854	10.496	11.742	11.054	10.486	12.062	11.370
18	10.403	11.122	10.868	10.401	11.037	10.628	10.401	11.011	10.781	10.403	11.582	11.089	10.399	11.853	11.152
19	10.471	11.366	10.851	10.478	11.200	10.736	10.481	11.035	10.877	10.482	11.186	10.912	10.480	11.591	11.015
20	10.591	11.231	10.914	10.593	11.219	10.943	10.593	11.212	11.051	10.595	11.136	10.831	10.591	11.489	10.984

Figure 50: Dynamic Experiment Data

Trial 1 %	Trial 2 %	Trial 3 %	Trial 4 %	Trial 5 %	Average %
34.810	45.449	26.368	24.262	45.283	35.234
53.327	50.133	24.594	22.710	42.344	38.621
58.114	60.500	34.486	20.435	43.243	43.356
45.053	40.901	54.217	38.005	64.712	48.578
50.681	44.459	56.000	41.774	40.401	46.663
18.013	16.755	27.086	28.787	21.847	22.498
54.822	57.178	54.604	41.229	40.646	49.696
49.807	41.407	46.552	40.293	53.605	46.333
43.364	40.205	46.305	48.485	62.684	48.209
40.379	45.777	38.215	53.488	50.171	45.606
31.001	42.678	41.526	37.033	43.816	39.211
35.055	44.741	54.040	34.277	41.459	41.915
42.341	65.997	44.309	41.594	42.778	47.404
30.769	42.361	39.216	46.354	53.304	42.401
50.072	41.185	64.534	51.394	45.132	50.464
52.477	50.582	40.493	44.580	55.232	48.673
32.695	59.197	35.000	55.217	43.909	45.203
35.327	64.308	37.705	41.815	48.212	45.473
57.542	64.266	28.520	38.920	51.845	48.219
49.531	44.089	26.010	56.377	56.236	46.449
43.259	48.108	40.989	40.352	47.343	44.010

Figure 51: Dynamic Experiment Results

D. SolidWorks Drawings

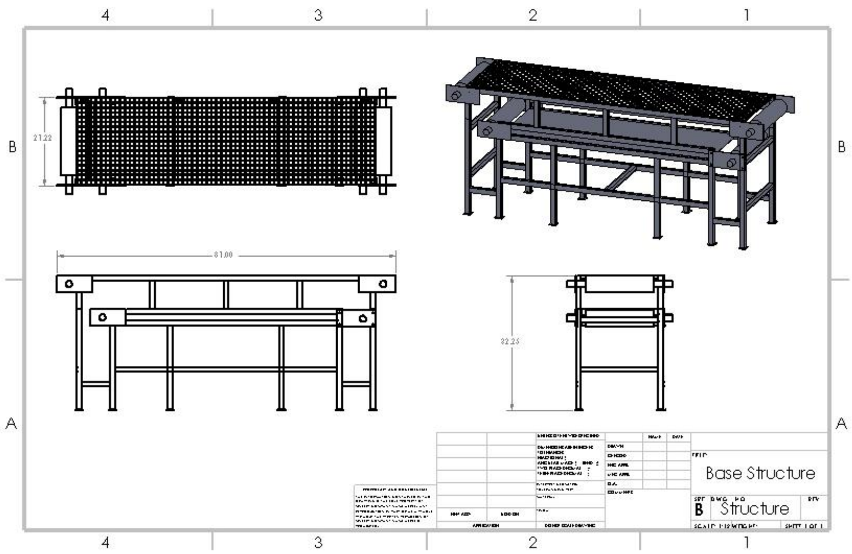

Figure 52: Prototype SolidWorks Drawing

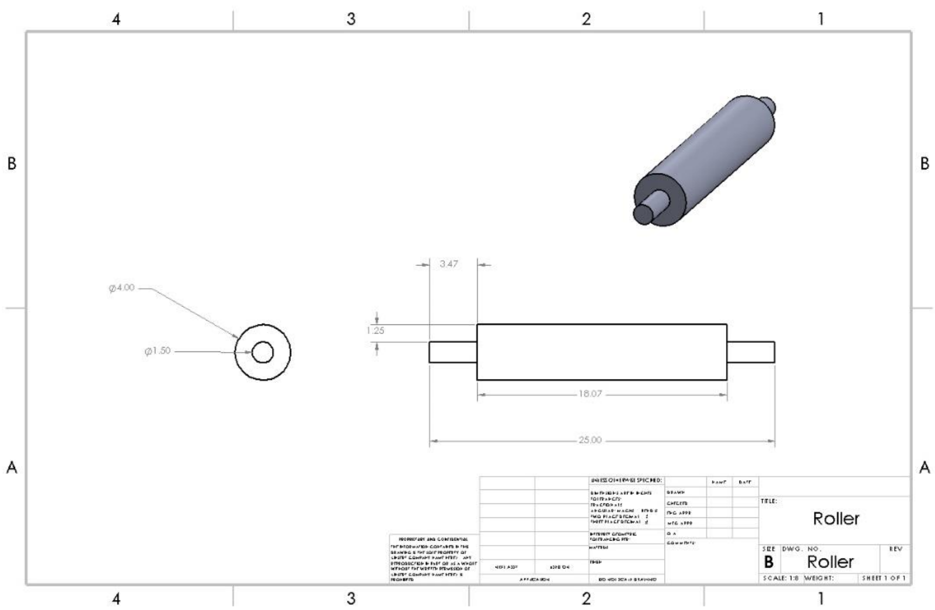

Figure 53: Roller SolidWorks Drawing

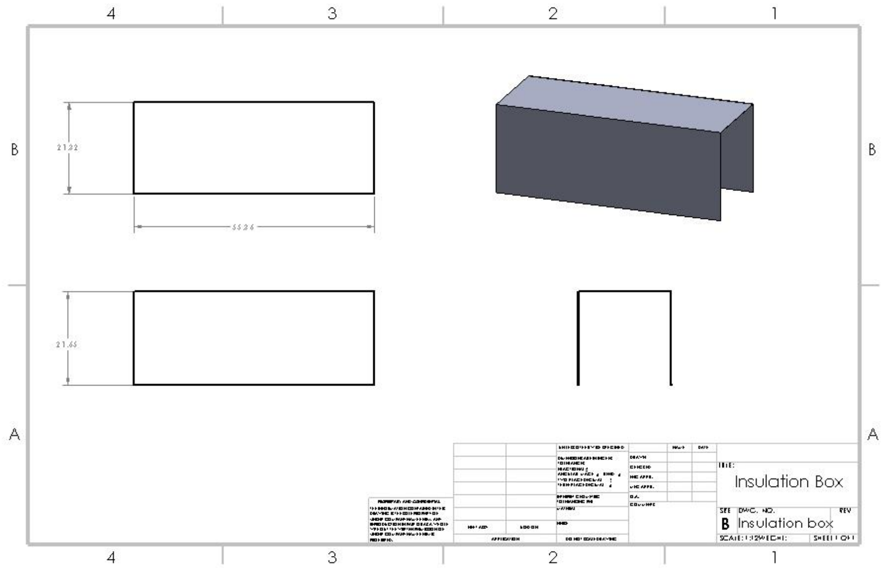

Figure 54: Insulation SolidWorks Drawing

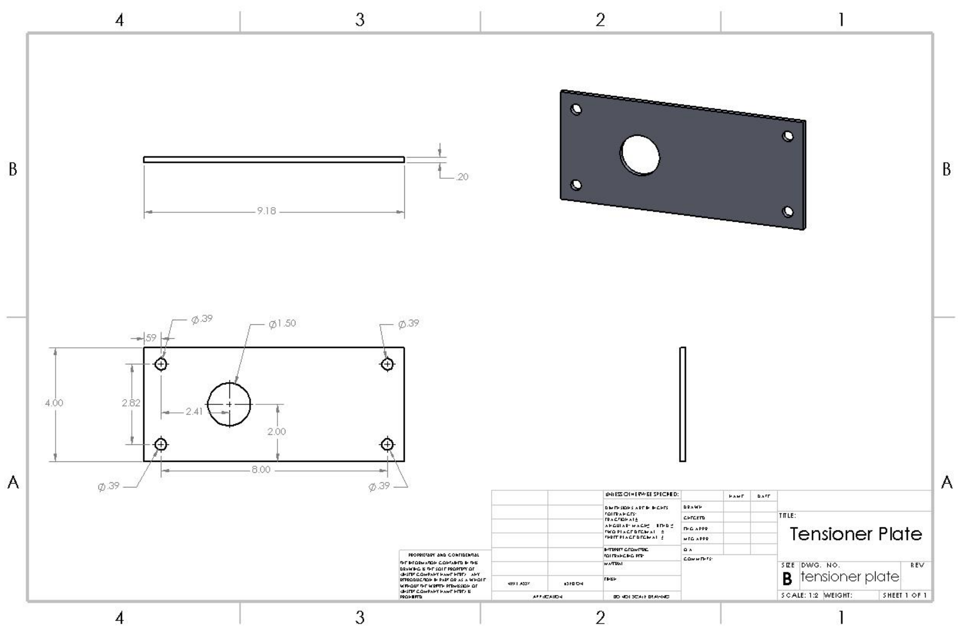

Figure 55: Tensioner Plate SolidWorks Drawing

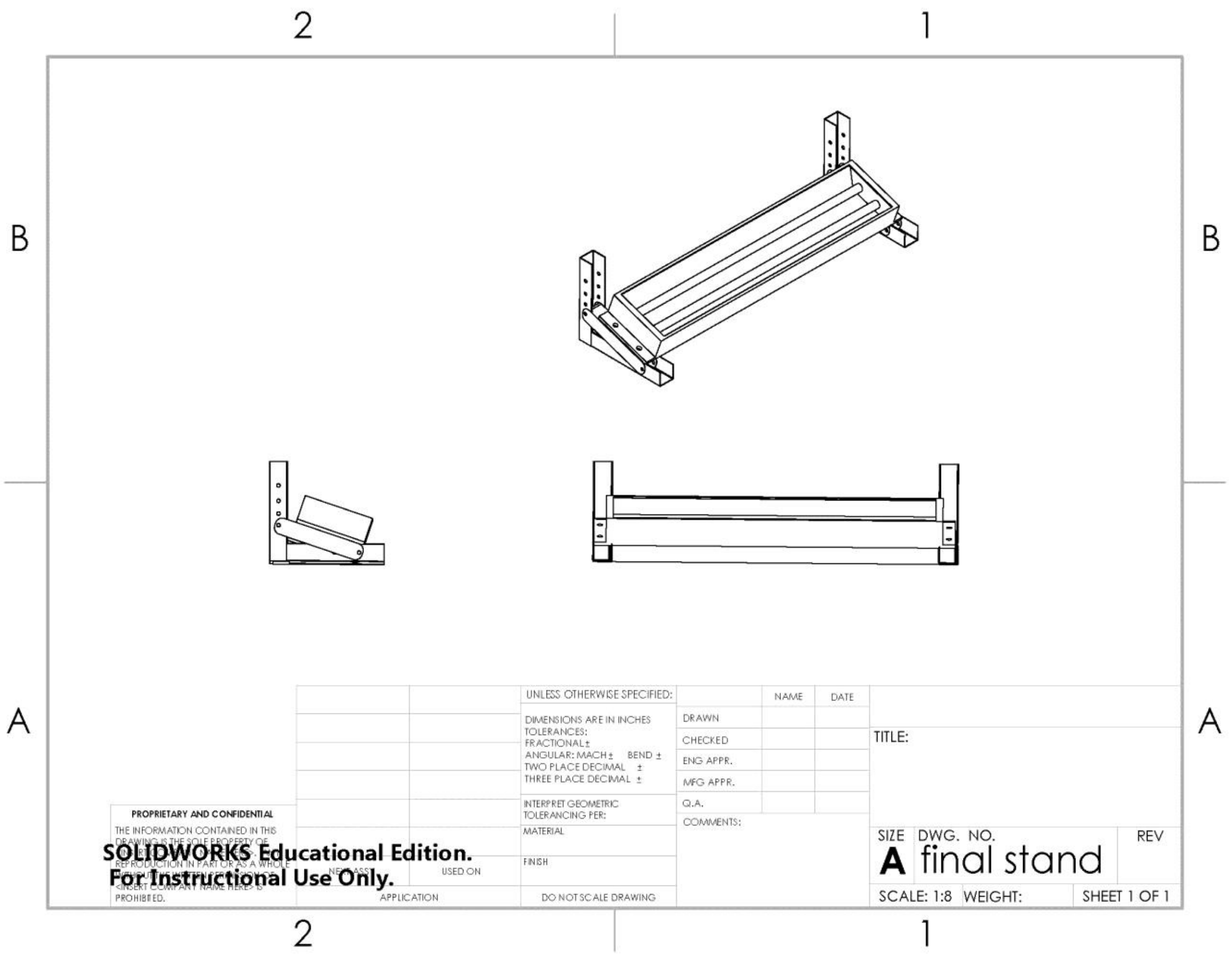

Figure 56: Final mounting system

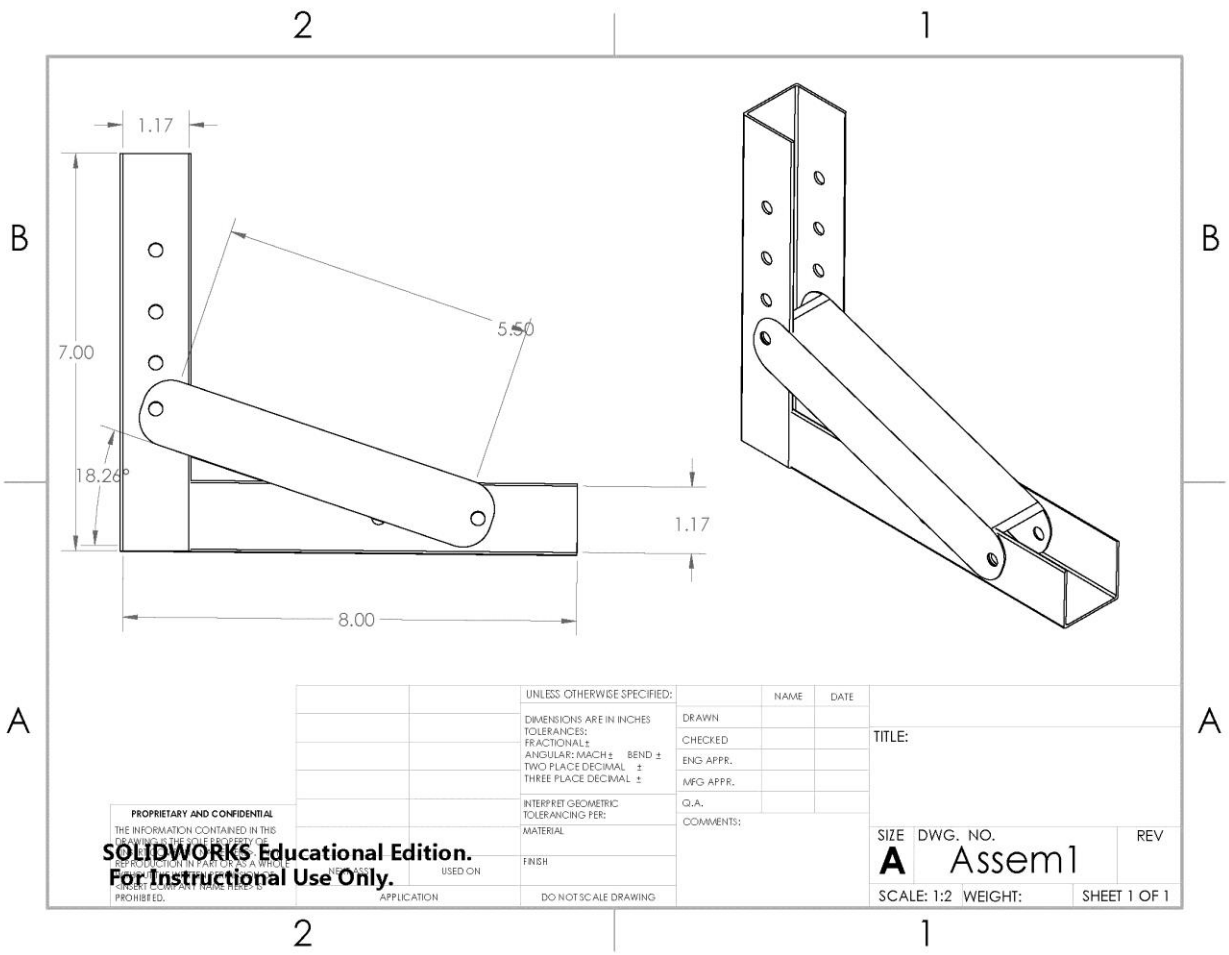

Figure 57: Mounting System Leg

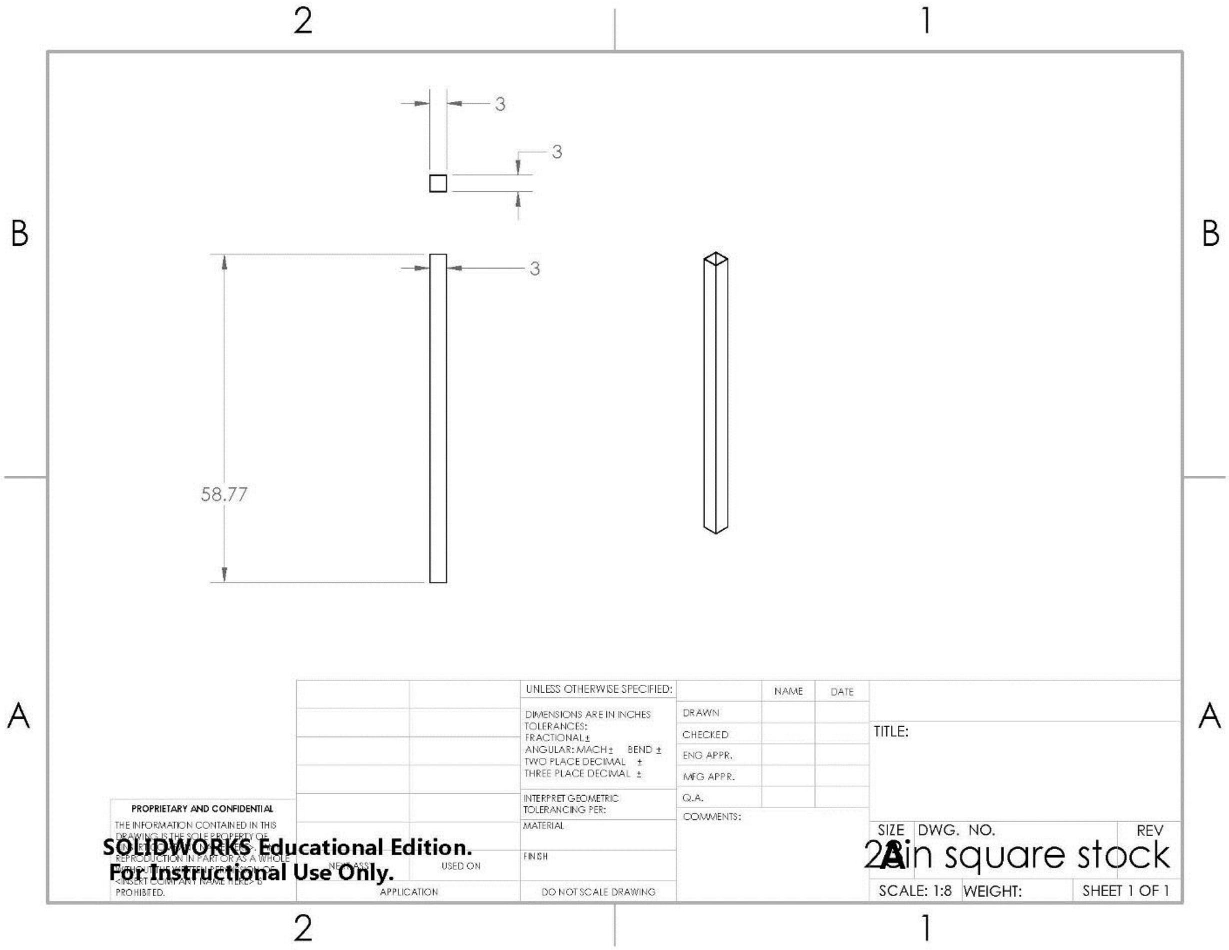

Figure 58: Square Stock

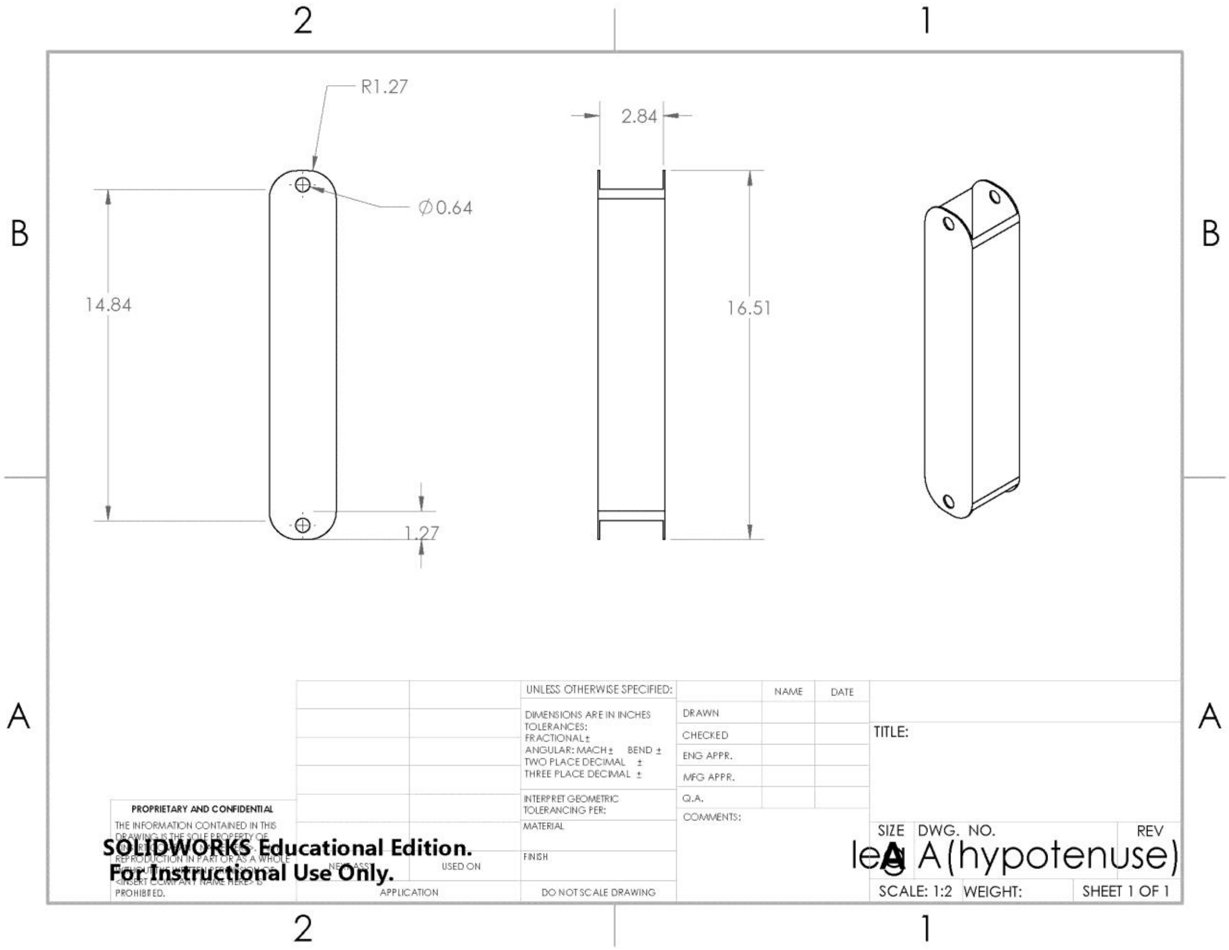

Figure 59: Mounting System Hypotenuse

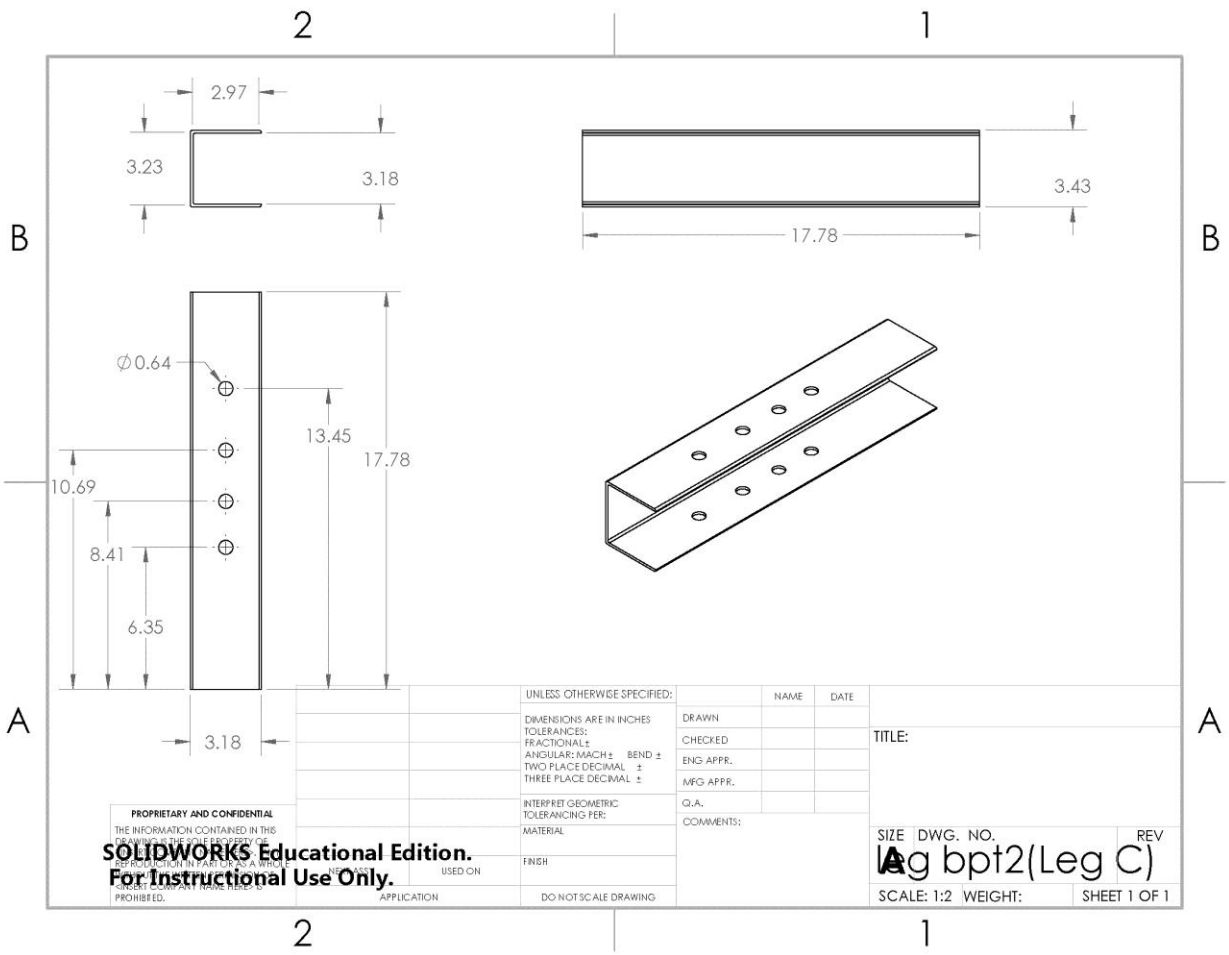

Figure 60: Leg C

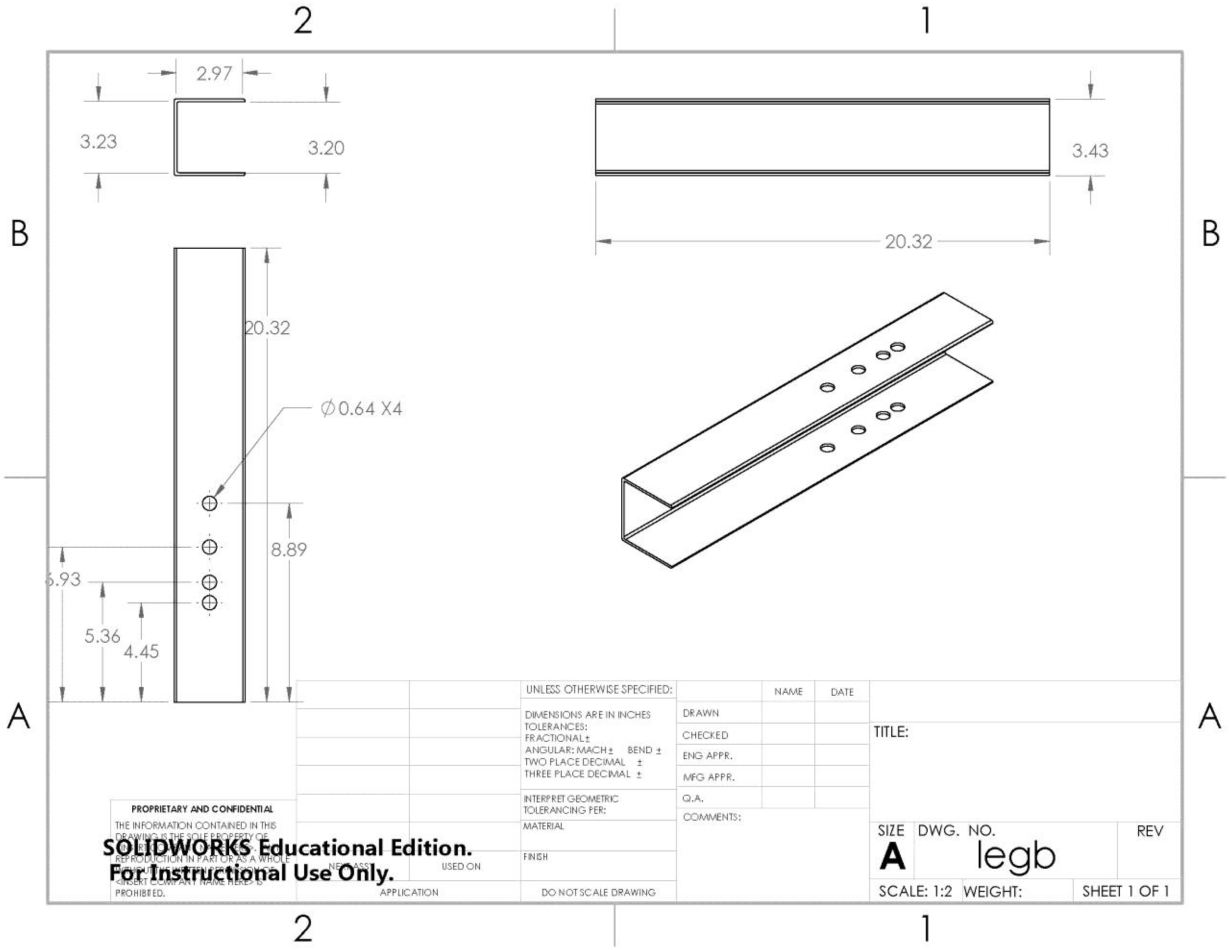

Figure 61: Leg B

E. Build of Materials

Table 19: Build of Materials

Materials	Dimension	Number	Price
Motor	Voltage: 12V Max RPM: 2000rpm	1	¥1253
Rectangular Stock	Cross Section: 2.5cm*5cm Length: 2m	4	¥300
Mesh Screen	Length: 1m Width: 53cm	2	¥30
Stainless Steel Plate	Thickness: 5mm Length: 1m Width: 0.6m	1	¥515
Square Stock	Cross Section: 3cm*3cm Length: 2m	16	690
Roller	Length: 0.406m	2	¥405
	Length: 0.459m	2	
L Bracket	Width: 48mm Height: 55mm	20	¥140
Infrared Tube	Power: 2000W	2	¥425
C Channel (Inner Width:3cm)	Length: 2.5m	2	¥174
	Length: 1m	4	
Total (CYN)			¥ 4,932
Total (USD)	$1 USD= ¥.150078 CYN		$740.18