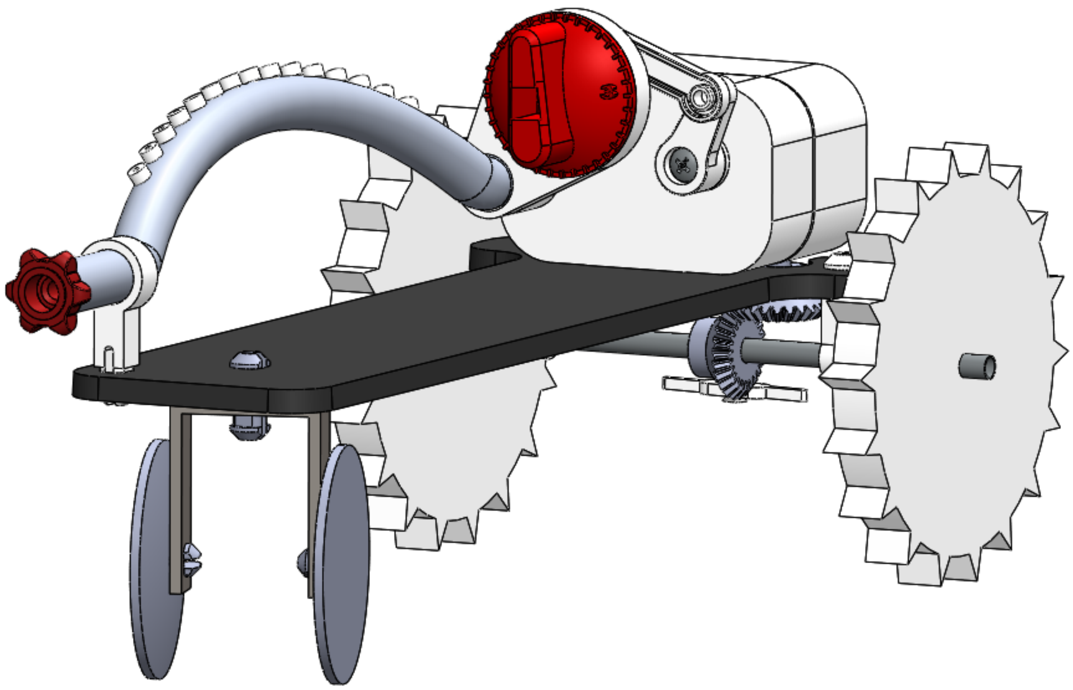
MCEN 5045 – Design for Manufacturability
Professor Dan Riffell

Mobile Oscillating Sprinkler



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Executive Summary

The mobile oscillating sprinkler in this report is a classic of lawn care. Since 1965, it has helped millions of homeowners effortlessly take care of their yard. This traveling sprinkler uses the power of water to navigate around the lawn following a customized hose path. It travels up to 200 feet and covers as much as 13,500 square feet. While automatic shut-off prevents water waste. Set the Rain Train up at the starting point, turn it on and watch it go to work.

This report details the design and analysis of a mobile sprinkler. A mobile sprinkler is a small sprinkler that drives around a lawn following the path of the garden hose set by the user. The project was motivated by our previous reverse engineering project where we studied an oscillating sprinkler that cost only $8. In contrast, existing mobile sprinklers cost $60 minimum online. Our primary design goal was therefore to design a mobile sprinkler that could be sold for under $25 using parts and concepts from the inexpensive oscillating sprinkler product. This goal was ultimately achieved, as our estimated selling price for the mobile sprinkler is $21.96.

Before designing the mobile sprinkler, we conducted some initial market and patent research, and created black box and glass box diagrams. Next, we laid out our design constrains that the sprinkler must weigh at least 3 pounds and travel about 20 feet an hour. The design, material selection, and process selection of all critical parts and sub-assemblies is also detailed below.

Once our design had been completed, we performed a cost analysis, design for manufacturability analysis, and design for assembly analysis. Of the 42 total unique parts in our assembly, 30 were plastic injection molded, 2 were rubber parts, 6 were standard parts, and 4 parts were metal made using either stock material, sheet metal forming, or casting. Our final estimated cost to manufacture the mobile sprinkler was $18.30, with a final sales price of $21.96 assuming a 20% profit margin. The breakeven point was estimated to be no more than 29,000 units. From our design for assembly analysis, we had a total part count of 65, with 168 total interactions. Our theoretical part efficiency was calculated to be 22% with a practical part efficiency of 72%.

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1 Project Background and Schedule

The purpose of this project was to design a novel product using concepts learned in class, including design for assembly (DFA) and design for manufacturing (DFM) analysis. Full computer aided design (CAD) models and engineering drawings were created for all product parts, while also taking into consideration how each part will be manufactured and how the product will be assembled. A cost analysis of the final product was calculated to determine the market viability of the design.

The entire novel design project, report, and presentation was completed over a 7-week period by our team of 4 graduate mechanical engineering students. Figure 1 below shows a Gantt chart we followed throughout the duration of the project:

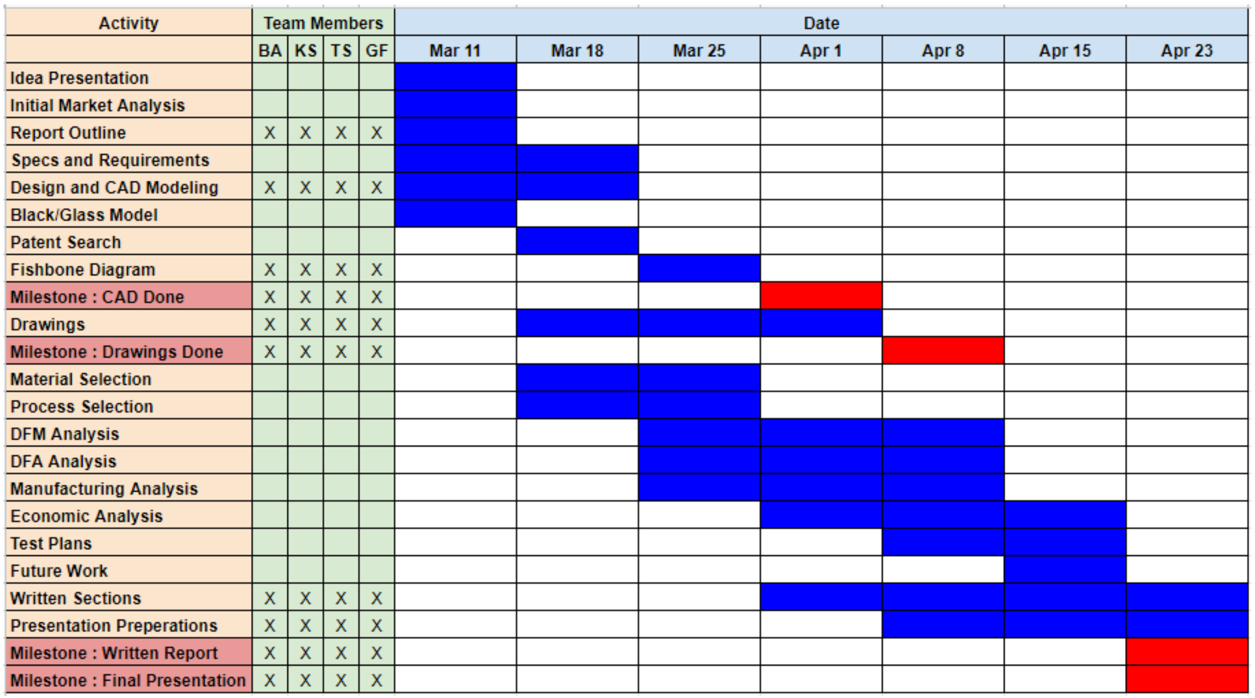


Figure 1: Gantt chart which details timeline of novel design project

During the first 3 weeks of the project, from March 11th to April 1st 2019, we developed the product design and modeled the design in CAD. While working on the design, material selection and process selection analysis was completed. During this initial period, we also worked on the first sections of the report, including the outline, initial market analysis, patent searches, black box, glass box, and fishbone diagrams, and specifications and requirements section.

In the following week from April 1st to April 8th, we completed all engineering drawings for all parts. On April 1st we started working on all post-design analysis, including DFA analysis, DFM analysis, manufacturing analysis, and cost analysis. In the last 4 weeks of the project, we wrote-up all remaining sections of the report, including the materials and process selection sections, test plans section, and summary and conclusion sections. During the last week of the project, the presentation slides were compiled, and the final report was formatted.

2 Reverse Engineering Project

Before this novel design project commenced, we completed a reverse engineering project on an Ace oscillating water sprinkler. In this project, the sprinkler was disassembled, and parts were fully modeled in CAD, and engineering drawings were created for all parts. We conducted a material and process selection analysis, cost analysis, DFA analysis, and DFM analysis on the sprinkler design.

Following our initial analysis, we made 3 design changes to address functional issues from online user comments, and to improve DFA and cost estimate metrics. A summary table of the DFA and cost estimate findings for both the initial sprinkler and redesigned sprinkler is shown below in Table 1.

Table 1: Summary Table of Ace Oscillating Sprinkler and Redesigned Sprinkler

Metric	Original Sprinkler	Redesigned Sprinkler
Total Unique Parts	26	21
Total Injection Molded Parts	21	17
Total Rubber Parts	2	2
Total Aluminum Parts	1	0
Total Standard Parts	2	2
Total Part Count	40	21
Total Number of Interactions	78	50
Theoretical Part Count Efficiency	10%	19%
Practical Part Count Efficiency	35%	62%
Total Cost to Manufacture	$7.15	$5.76
Estimated Sales Price	$8.51	$6.90
Actual Sales Price	$7.99	N/A
Break Even Point	30,000	30,000

For our novel mobile sprinkler design described in the following sections, we incorporated many parts of the existing oscillating sprinkler design. For detailed documentation on the existing oscillating sprinkler design and our 3 redesigns, please see our “Reverse Engineering of an Oscillating Sprinkler” report [1].

3 Preliminary Design Research

3.1 Design Motivation

When brainstorming ideas for our novel project, we wanted to design a new sprinkler that built off the successes of the Ace Oscillating Sprinkler (mainly the low cost of the sprinkler), but functioned in a new and improved way. We thought the most obvious design improvement would be to prevent the user from placing the sprinkler in different spots in order to cover the entire lawn. We discovered some mobile sprinkler designs online, which travel the path of the hose laid out by the user around a lawn. A picture of a mobile sprinkler made by Nelson is shown below in Figure 2 [2], and the initial patent search that we conducted is detailed in Section 3.4.

Figure 2: Nelson 818653-1001 travelling sprinkler

We thought that this approach to a lawn sprinkler was ingenious because by allowing the user to lay out the hose in a specific path almost any size and shape of lawn can be completely watered without having to move the sprinkler, as is the case with an oscillating sprinkler.

Our motivation to design a new mobile sprinkler came from the high price point of existing sprinklers. The Nelson sprinkler pictured above was priced at $60, and most other designs were at least $90 [2]. Considering that our ace oscillating sprinkler was sold for only $8, and our redesigned sprinkler has an estimated sale price of $6.90, we thought we could build off our existing oscillating sprinkler, reusing many of the existing injection molded parts, and create a new mobile sprinkler design to sell for significantly less money. We decided that our goal would be to create a design which had an estimated sales price of no more than $25, which would be 50% the cost of other existing products.

3.2 Black Box and Glass Box Diagrams

One of the initial steps in the design process was to look simply at the inputs and outputs of a typical mobile sprinkler design. We accomplished this with a black box diagram, which is pictured below in Figure 3.

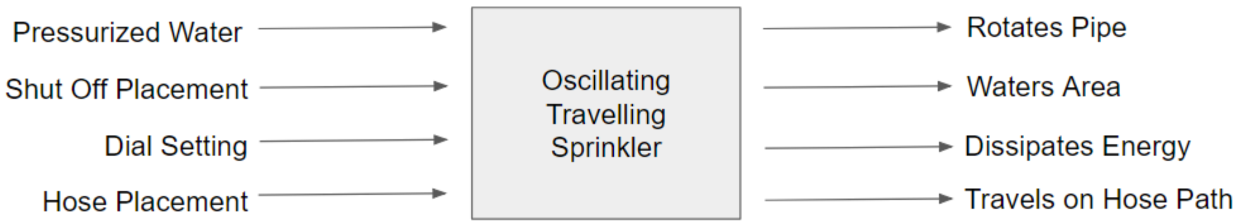


Figure 3: Black box diagram of typical mobile sprinkler design

We determined four inputs and four outputs to the system. The most obvious input to the sprinkler is pressurized water through a garden hose, which not only provides the water needed for watering the grass, but also provides all the energy to the sprinkler in the form of pressure. The pressurized water (typically 60 to 80 psi) powers both the transverse motion of the sprinkler and the motion of the hose, with no additional electrical power required.

The other 3 inputs to the mobile sprinkler are by the user. The most important input is the layout of the hose, which will determine the path of the sprinkler. The sprinkler starts travelling at the end of the hose, and slowly follows the hose path back to the spicket. To stop the motion of the sprinkler so it does not run all the way up to the spicket, the user places a stopper part around the hose. When the sprinkler runs over the stopper, the sprinkler will automatically shut off. Some mobile sprinklers also have a fourth input, which might be some sort of dial (in the case of an oscillating design) which indicates how much the water should spray side-to-side from the sprinkler. More expensive designs also have a dial to control the travelling speed.

There are also four primary outputs of a typical mobile sprinkler. The first two outputs are the motion of the watering pipe, and transverse motion of the sprinkler. Both of these motions are powered by water pressure. The third input is simply the water that comes out of the sprinkler pipe, which lands on the grass and waters the lawn. The final output is any miscellaneous dissipated energy from heat, sound, or sudden pressure drops in the water.

Once the inputs and outputs of a mobile sprinkler were understood, the internal subsystems of a mobile sprinkler were researched to determine how the sprinklers actually work. The subsystems are summarized below in Figure 4 in the glass box diagram.

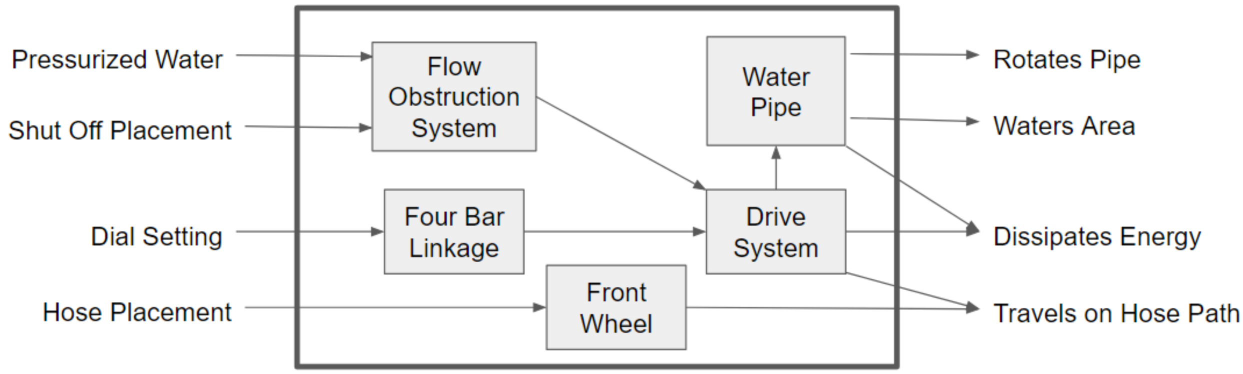


Figure 4: Glass box diagram displaying more of a focus on the inner subsystems

The simplest subsystem is the front wheel. The front wheel wraps around the diameter of the garden hose, and therefore turns the sprinkler to follow the path of the hose. The pressurized water feeds into three main subsystems: first the flow obstruction system, then the drive system, and finally, the watering pipe. The flow obstruction system is a simple stopper, which serves to cut off the water when the sprinkler drives over the shut-off ramp. If the water is cut off, no more water can come out of the water pipe, and there is no pressure power provided to the drive system, so all motion stops. In the drive train, the pressure of the water spins a small turbine, which powers a gear system. This gear system is connected to the back wheels of the sprinkler, which drives the transverse motion. In the case of an oscillating sprinkler, the gear system is also connected to the main water pipe in order to rotate it. After the water passes through the drive system, it runs through the water pipe, where it escapes through nozzles and onto the lawn.

The final subsystem of the mobile sprinkler is the bar linkage assembly, which for an oscillating sprinkler, is connected to the control dial. The bar linkage restrains the rotational motion of the water pipe and is therefore connected to the drive train.

3.3 Market Analysis

Lawn sprinkler market continues to witness promising growth, with more consumers focusing on sustainability, seeking their landscaping to potentially conserve water. Over the past five years, the Water Supply & Irrigation Systems in the US industry has grown by 0.8% to reach revenue of $79bn in 2018. In the same timeframe, the number of businesses has grown by 1.5% and the number of employees has grown by 1.6% [3]. Figure 5 below shows the summary of data gathered during the market analysis.

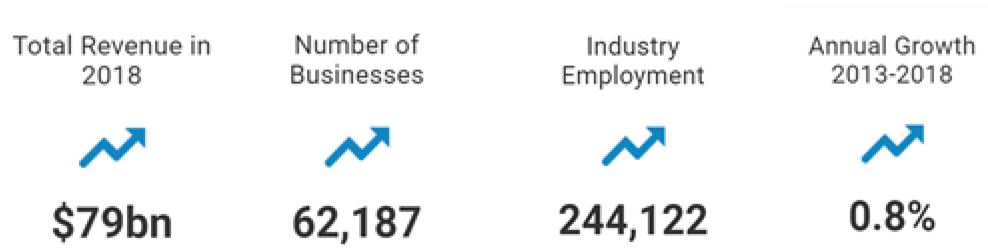


Figure 5: Water supply & irrigation systems industry trends

The environmental protection agency (EPA) has expressed concern about water waste due to overwatering from sprinklers. This has led lawn sprinkler manufacturers to step up efforts in development and marketing their water-efficient lawn sprinkler variants. The mobile sprinkler has many advantages. One of the crucial advantages is that the sprinkler is independent of electricity. You do not need electricity to operate the unit. It drives only the head of water, which can be regulated independent of electricity. You do not need electricity to operate the unit. It controls only the water that can be adjusted. It reduces manual labor and replaces the stationary sprinkler. The system is capable of replacing 2-3 conventional sprayers. You do not need to rearrange it, because with the help of wheels, it moves in the given direction. You can set not only the straight position of the hose, but also the turns, which is very convenient. The mobile sprinkler will move in any direction, easily overcoming twists and turns. It has the ability to switch off automatically. Due to the presence of a stopper for the hose, the unit stops and stops feeding water. It is easy to attach and remove. In addition, it is reusable. A long service life is guaranteed because cast iron models do not break, do not crack from the effects of ultraviolet rays and are not afraid of rain and wind. For winter, you can store the hose in the garage.

The mobile sprinkler also has drawbacks. Primarily, it is difficult repair. Inside there are plastic gears which can break. It is difficult to find individual original spare parts, so if you fail, you may need to buy another mobile water sprinkler. It is also difficult to stop its motion in wet soil. If there is wet ground with a lot of water, the wheels will stick to the dirt and will stop moving. Therefore, when using it, it is prudent to lay grass or hard strips under the route.

It should be noted that other products exist on the market for a moving water sprinkler, this product differs from those in that it performs the process more effectively than other similar products. The price range for their products vary between $80 to $3000.

3.4 Patent Research

A patent search was conducted prior to design to gain familiarity with products that are already on the market attempting to accomplish the same task. This also gives insights into there could be any possible legal issues if our product goes to market. Several traveling or mobile sprinkler designs were found and are detailed in Sections 3.4.1 - 3.4.3. The first design was quite different from our initial thoughts mainly that it used a cable and winch system in order to move the sprinkler about the yard. The second similar design found was used the hose to guide the system similar to our design but this whole assembly was much more complicated with a four-wheeled front end that pivots in order to steer. The third design we found that was relevant to our design is the patent that the company Nelson was awarded. This design has a simple rotating sprinkler head on the top though and we feel our oscillating design waters the area much better. Our research showed us that our design is still a novel and unique design that could most likely attain a patent for the oscillating motion while traveling throughout the yard.

3.4.1 Traveling irrigation sprinkler - US4003519A

A traveling irrigation sprinkler has a water-powered radial inflow turbine for driving a winch that pulls the sprinkler along a path of travel. Water is supplied to a sprinkler gun either directly from an inlet conduit, or indirectly by passing it through the turbine. A diverter valve proportions the direct and indirect flows and provides a first means of controlling the travel speed of the sprinkler. A transmission drivingly interconnects the turbine and the winch and provides a second means of controlling travel speed. The turbine includes a vanned runner and a scroll which circumferentially surrounds the runner to deliver water at a substantially uniform velocity to the periphery of the runner. A figure from the official patent is shown below in Figure 6. [4]

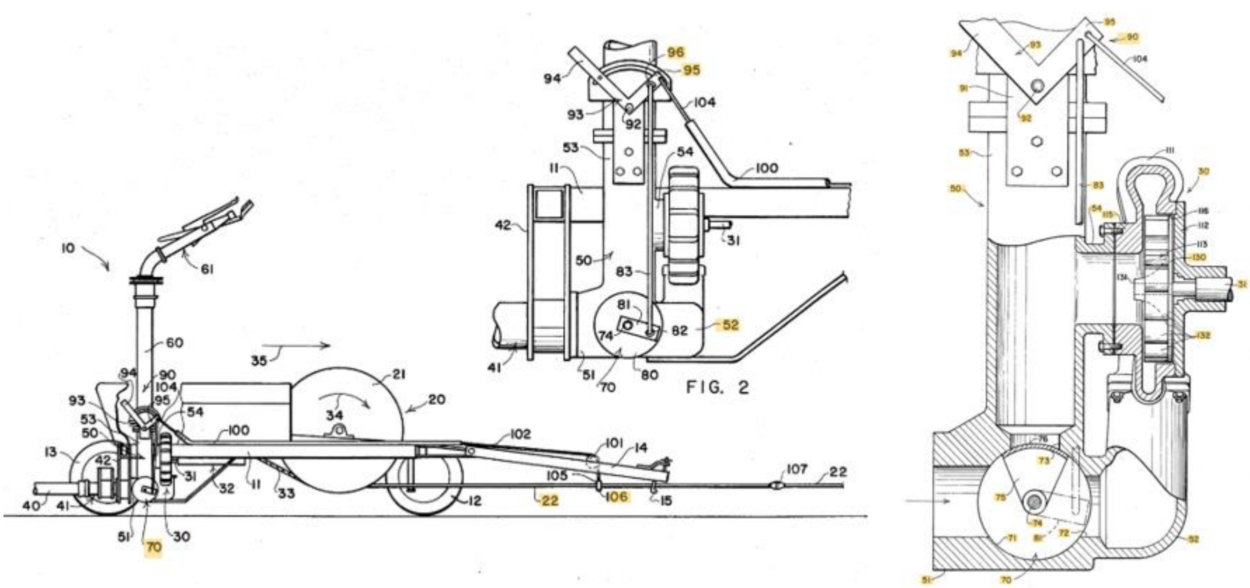


Figure 6: Design that utilizes a winch and cable to translate

3.4.2 Traveling irrigation sprinkler and method of irrigation sprinkling - US3235009A

This invention relates to sprinkling and more particularly to an improved method and apparatus especially useful in agricultural irrigation of fields and the like. The sprinkler is guided in its movement through the field by sensing the elongated contour of a furrow formed in the field. In this way the present system is readily applicable to existing conditions and particularly to those elds where rows of crops are planted. The furrow may either be formed by the use of the apparatus itself or with conventional furrow-forming equipment separate from the present apparatus. A figure from the official patent is shown below in Figure 7. [5]

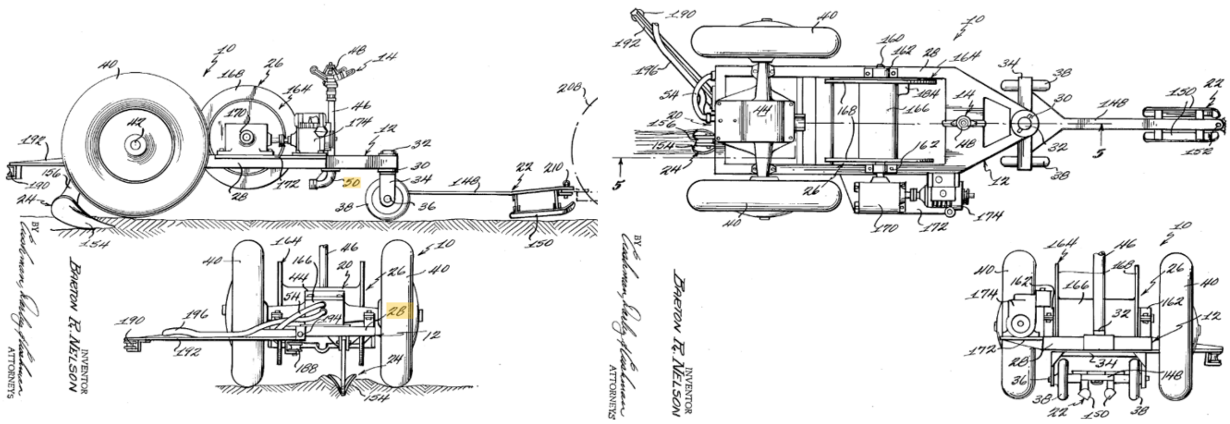


Figure 7: Design that utilizes an agricultural furrow to steer

3.4.3 Impeller driven traveling sprinkler - US6604697B1

The sprinkler has a support body with a drive unit which drives two rear wheels. The drive unit is powered by water pressure supplied through a hose which is coupled to the drive unit via a hose coupler. The drive unit has a cylindrical drive chamber with circular impeller in fluid communication with the hose coupler. The impeller is rotated by the water pressure and is mechanically connected to a lateral shaft. The shaft is connected to the rear wheels. Reduction gearing from the impeller to the shaft governs the speed of the sprinkler. The reduction gearing is achieved through a series of sun gears, carrier disks and planet gears. The drive unit also has an outlet which has a socket which allows the exit of the pressurized water. The socket allows the insertion of any variety of sprinkler heads. Thus, the sprinkler allows a variety of water distribution patterns. The sprinkler is propelled by water pressure rotating the impeller and eventually the rear wheels. A figure from the official patent is shown below in Figure 8. [6]

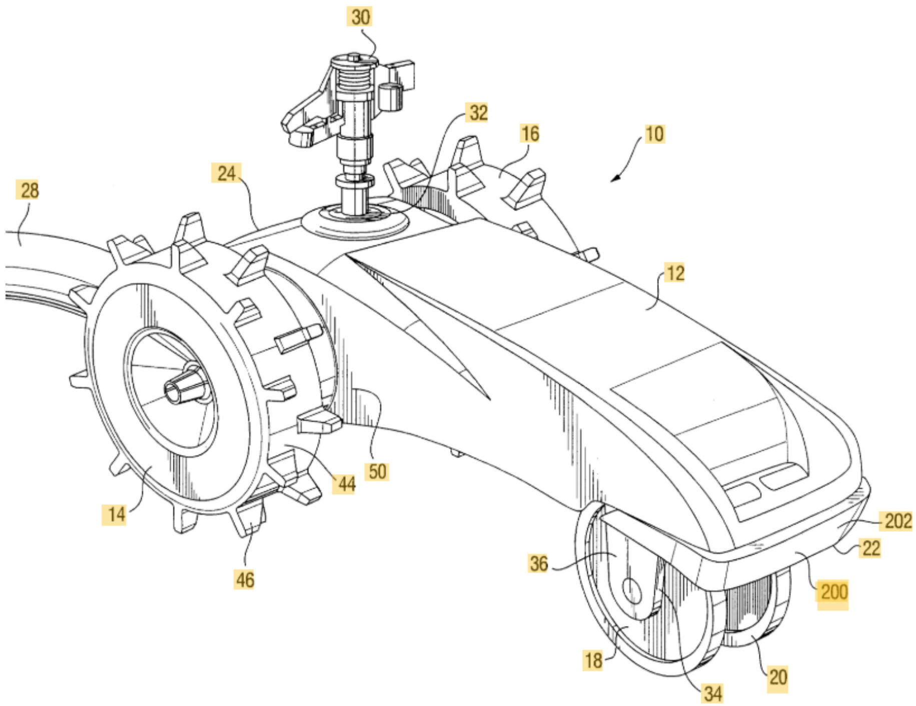


Figure 8: Design that utilizes a rotating sprinkler head for watering

4 Design Specifications

4.1 Weight Requirement

The mobile sprinkler design utilizes the input hose as a path guide by following the predetermined hose path determined by the user. This means the mobile sprinkler also has to drag at least half of the hose across the yard as it moves and sprays the water. One important specification of the sprinkler because of the hose guide design is the minimum weight of the sprinkler assembly in order to react against the friction force of the hose. If the sprinkler does not have enough mass then it will simply slip out on the grass when the water pressure spins the rear axle.

The minimum weight of the sprinkler is determined by estimating the friction force required to move the hose throughout the yard. The total weight of the hose will determined by assuming a ⅝" inner hose diameter being completely filled with water. A 50 ft standard rubber hose is 8 lbs so half of that length will contribute 4 lbs. A large coefficient of friction in the calculation is assumed since the hose is made of rubber. Calculation of the weight necessary to react against the friction force is shown below:

Water Weight = Volume * Density **Equation 1**

$$= \left(\frac{5}{16}^{2} * \pi * 25 * 12\right) [\text{in}] * 0.0361 \; [\text{lbs}/in^{3}] \; = \; 3.3 \text{ lbs}$$

Friction Force = Normal Force * μ **Equation 2**

= (Water Weight + Hose Weight) * μ = 7.3 lbs. * 0.4

= 2.92 lbs.

The entire mobile sprinkler assembly must therefore be at least 2.92 lbs in weight to overcome the friction force and drag the length of the hose through the grass.

4.2 Drivetrain Specifications

One of the initial design specifications that needed to be determined was rotational velocity of the rear axle to provide a translational velocity that is desired for the moving sprinkler. It was estimated that a sufficient speed that allows for a full watering of the lawn would be approximately 20 feet per hour. With an assumed rear wheel diameter of four inches the rotational velocity of the axle is easily determined as seen in Figure 9.

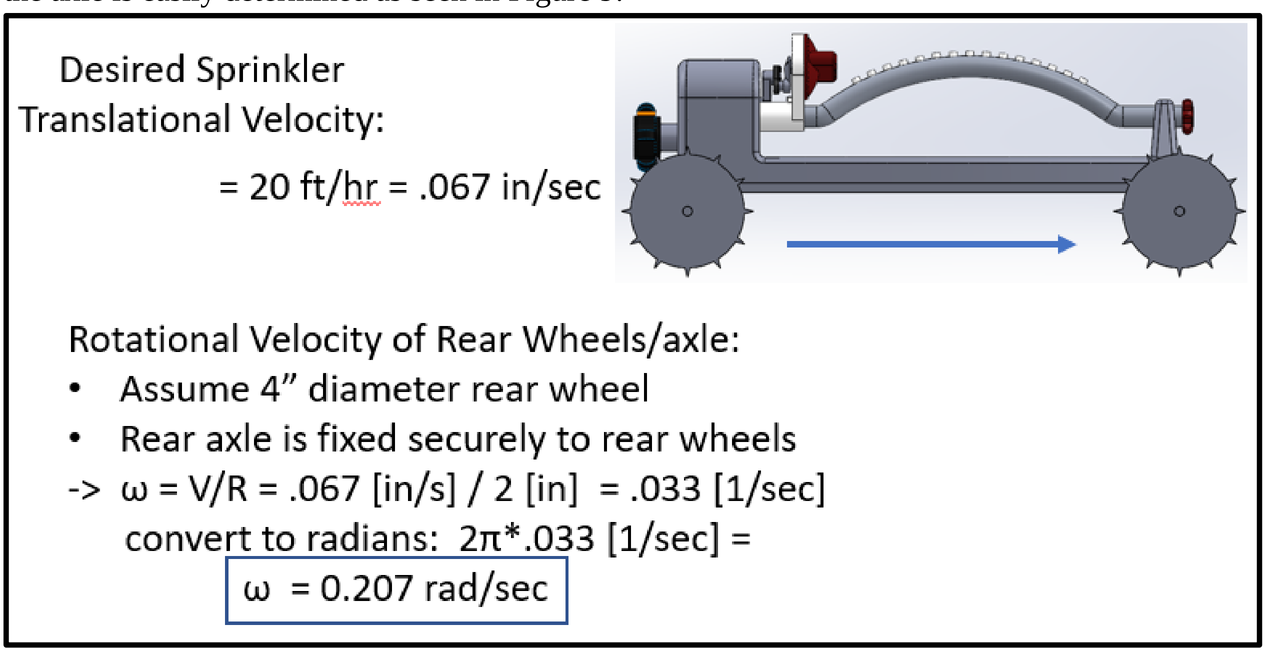


Figure 9: Calculation of rear axle rotational velocity

The new mobile sprinkler design will utilize an additional gear that mates with the same gears that drive the oscillating water pipe. The gear ratio of the new gear to the existing worm gear will be chosen to provide the desired rotational velocity to the rear axle. Empirical testing of the oscillating sprinkler was conducted during the reverse engineering effort to determine the rotational velocity of the gears that drive the dynamic motion of the sprinkler. This empirical data was used to calculate a gear ratio that results in a translational velocity of the sprinkler that is desired. Figure 10 below shows how the empirical testing of the sprinkler was used to calculate an approximate rotational velocity of the main worm gear. Then the final determination of the number of teeth in the new gear is shown in Figure 11. An important assumption that was used for the final determination of the gear ratio was a reduction of 1.5 in the rotational velocity of the worm gear due to the additional force required to power the redesigned the sprinkler movement.

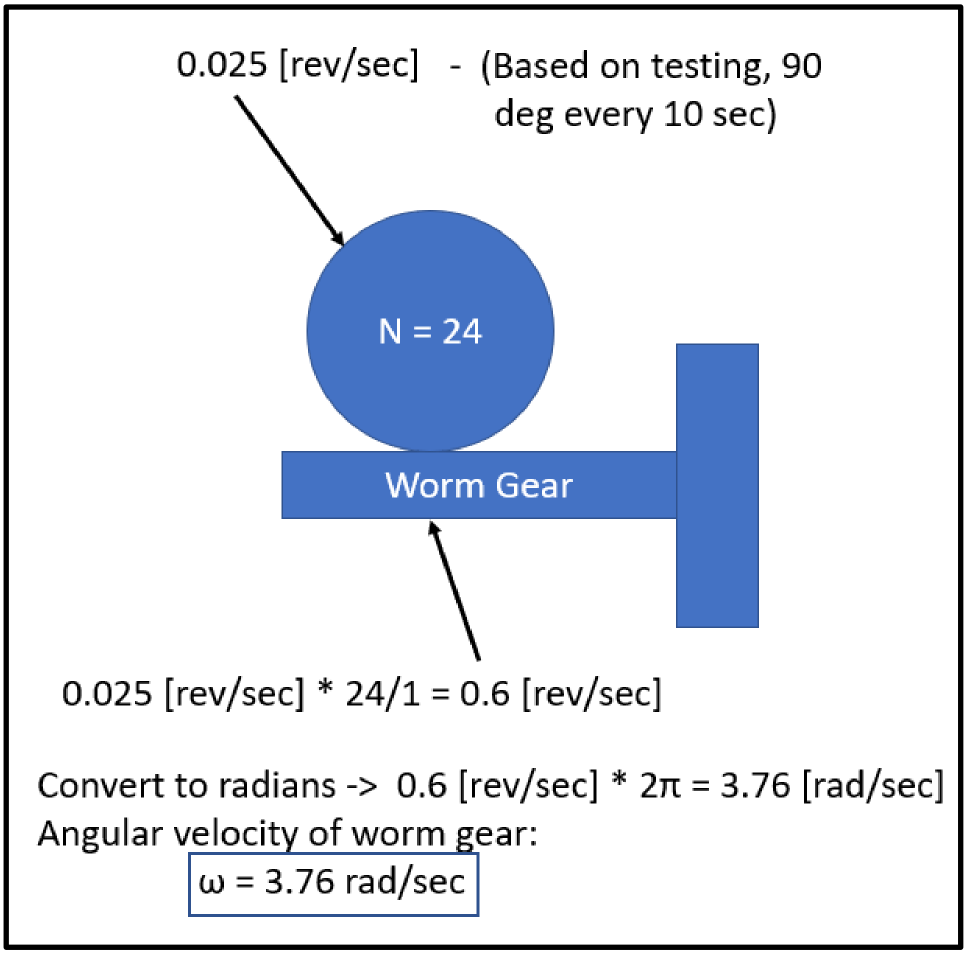


Figure 10: Determination of the main worm gear rotational velocity

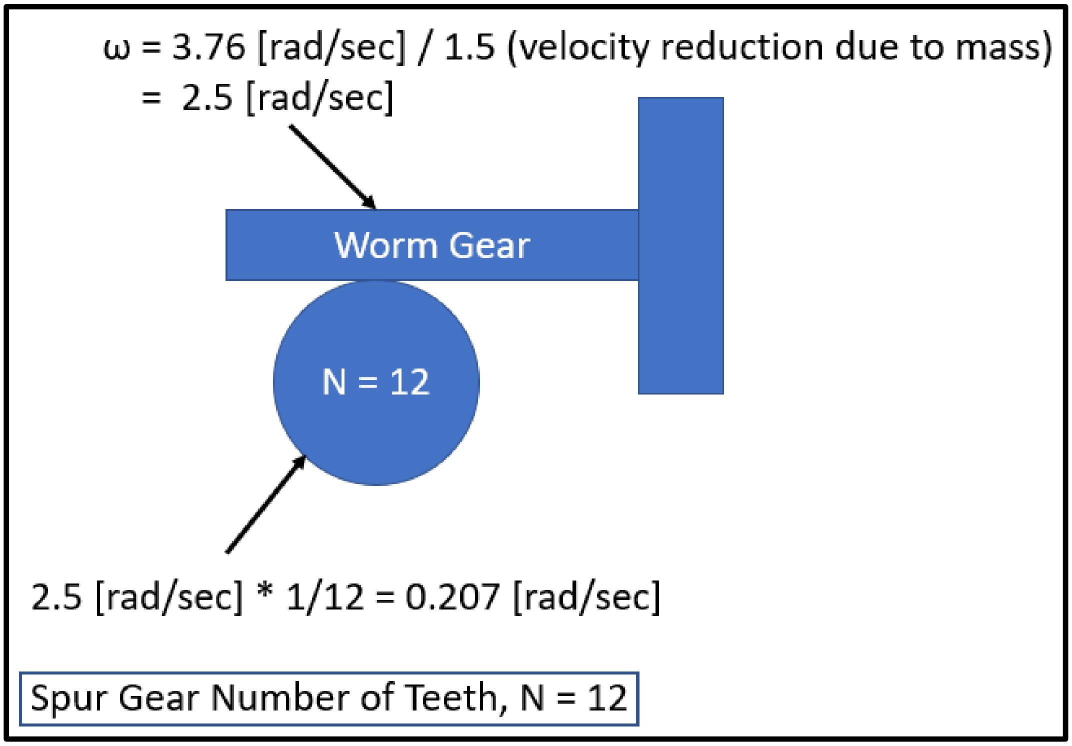


Figure 11: Calculation of the new spur gear teeth number

5 Novel Design Overview

Our final mobile sprinkler design including an exploded view is pictured below in Figure 12:

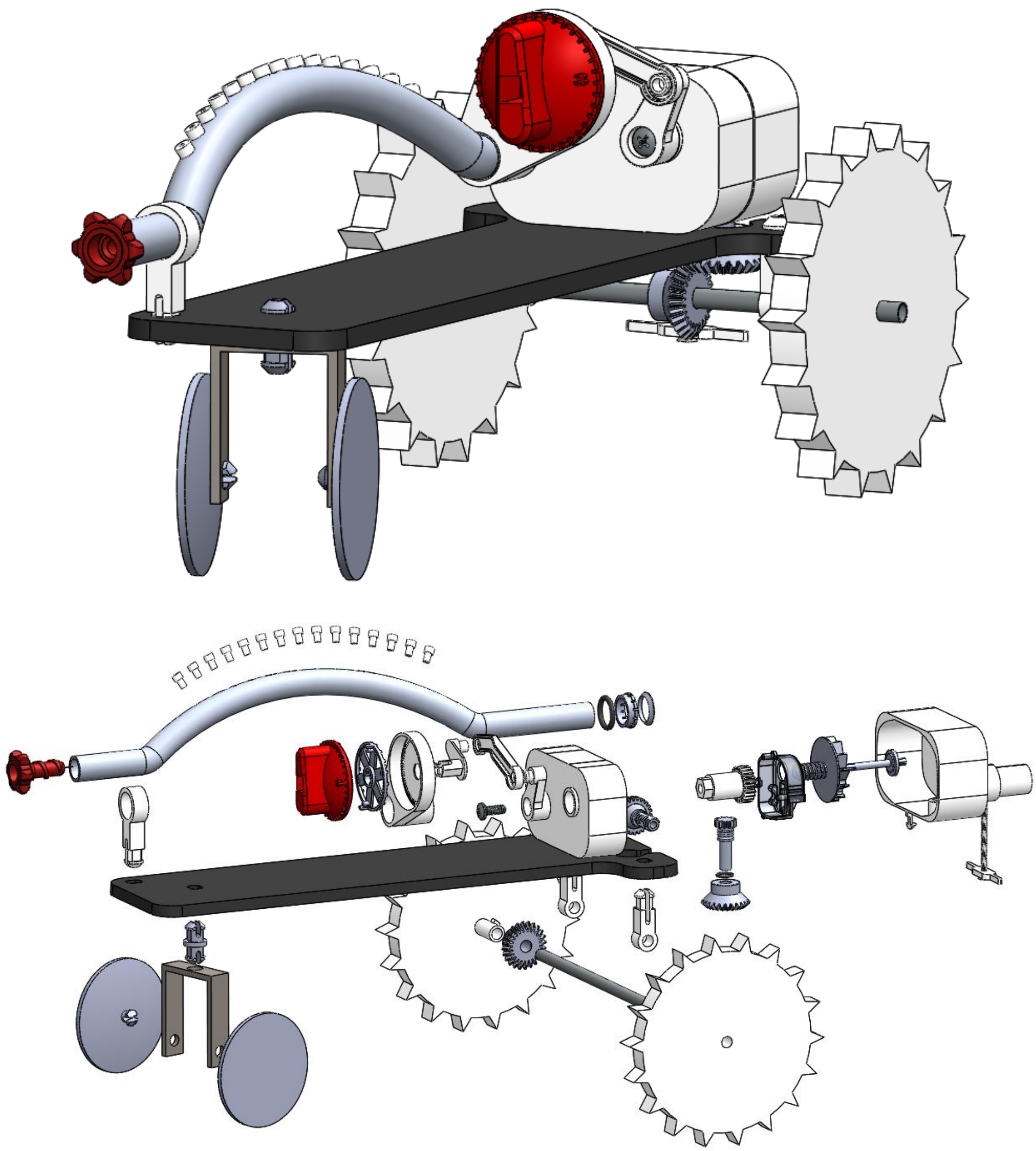


Figure 12: Assembly View and Exploded View of Final Mobile Sprinkler Design

A fishbone diagram is included below in Figure 13, which details all subsystems and lists all major part names:

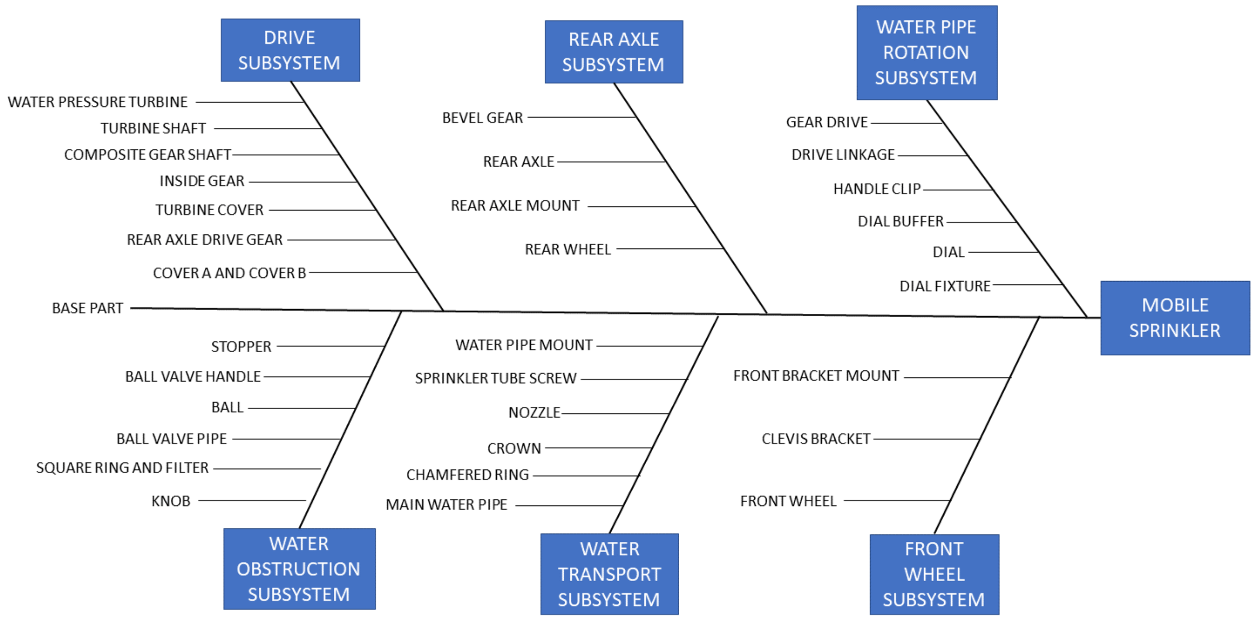


Figure 13: Fishbone diagram containing the subsystems and major components

There are 6 major subcomponents of the mobile sprinkler, all of which are connected to the sprinkler base part (GCI-001). The design on this part is detailed in section 6.3 below. The first subsystem is the water obstruction system, which includes a ball valve that blocks the flow of water when the sprinkler drives over the plastic stopper. The design of this subsystem is detailed more in section 6.4.

The second subsystem is the drive subsystem. After the water runs through the ball valve, it spins a turbine that powers a gear system that controls both the forward motion of the sprinkler and the rotation of the main water pipe. The drive system has mostly remained the same as the previous Ace oscillating sprinkler subsystem, and all changes to this drivetrain are detailed in section 6.1.

The third subsystem is the real axle, which contains the two back wheels that drive the motion of the sprinkler. The fourth subsystem is the front wheel subsystem, which fits around the diameter of the garden hose and rotates with the hose to follow a user determined path. Both the front wheel and rear axle designs are detailed in section 6.2.

The fifth subsystem is the water transport system. After the water runs through the ball valve and water pressure turbine, it enters a main water pipe that is connected to 15 nozzles that distribute the water of the sprinkler and onto the lawn. In our previous report, we had thought that this entire subsystem, including the water pipe, nozzles, and end screw, could be injection molded as one part. However, after researching injection molding further, we determined that it would be impossible to make such a part. Attempts to redesign the part to make injection molding a viable option also failed. We concluded that Ace oscillating sprinkler design was the most inexpensive manufacturing option. The water transport subsystem on our mobile sprinkler is therefore unchanged from the original oscillating sprinkler.

The final subsystem is the water pipe rotation subsystem. This system, like the rear axle system, is also driven by the drive system, and rotates water pipe side to side to better distribute the water over the grass. This subsystem also includes a dial which the user can turn to adjust the range of rotation of the water pipe. This subsystem is also unchanged from the previous ace oscillating sprinkler product.

In principal, our mobile sprinkler is similar to existing mobile sprinklers on the market. Our primary goal however was to design to reduce price, and therefore all components of the sprinkler are made either from inexpensive manufacturing processes: injection molding, casting, or stock material. Unlike some mobile sprinklers on the market, our sprinkler does not have an adjustable travel speed, but instead has an adjustable range of rotation of the main water pipe. If users set a large range, the sprinkler will water more lawn area from side-to-side of the sprinkler, but will water this area more sparsely. If the user sets a small rotation range, the sprinkler will water less area, but this area will be watered more densely. Therefore, using the single dial, the user can better define the area to be watered and also the density of the watering.

6 Critical Component Design Additions

6.1 Drivetrain

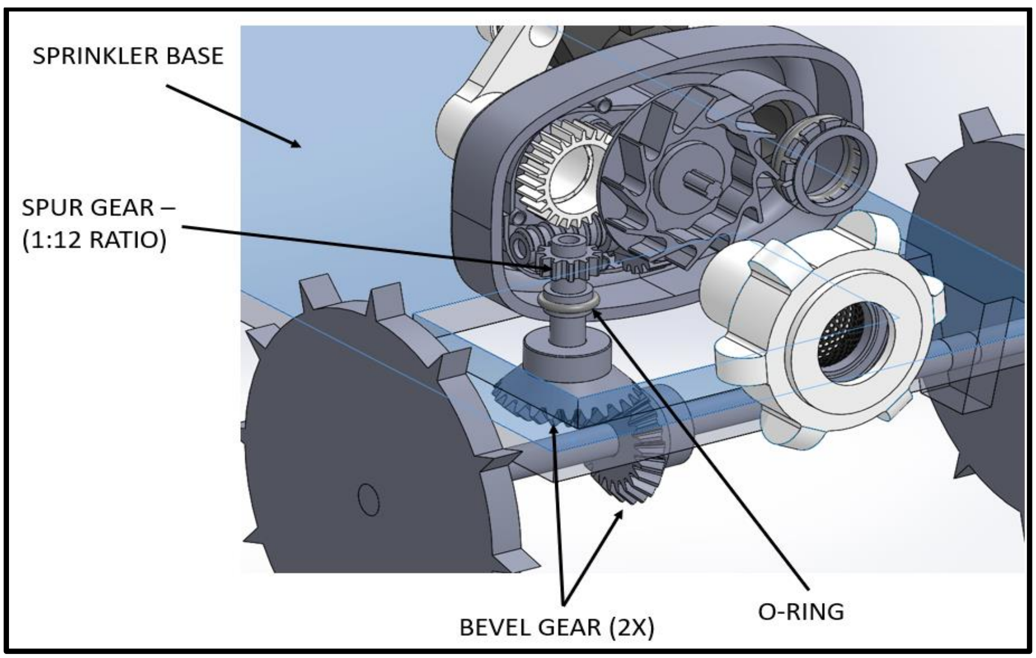


Figure 14: Sprinkler assembly viewed from rear end with PLA-056 (COVER B) hidden

A critical new addition to the mobile sprinkler design is the method in which the sprinkler assembly will translate across the lawn. It was desired to keep the design completely powered by water pressure so the design integrates a gear that protrudes down from gear box housing to a rear axle attached to the sprinkler base. At the base of the gear shaft is a bevel gear that mates with another bevel gear attached to the rear axle. A figure of this new design is shown below in Figure 14.

The new gear is held in place by a boss in the COVER B component. This feature locates the gear in the correct position above the rear axle of the assembly as well as provides a watertight seal between the gear and the housing. The boss has a snap-in feature for the gear that prevents any need for fasteners which decreases the assembly time and reduces the number of parts in the design. A cross-sectional view of the new gear and housing configuration is shown below in Figure 15:

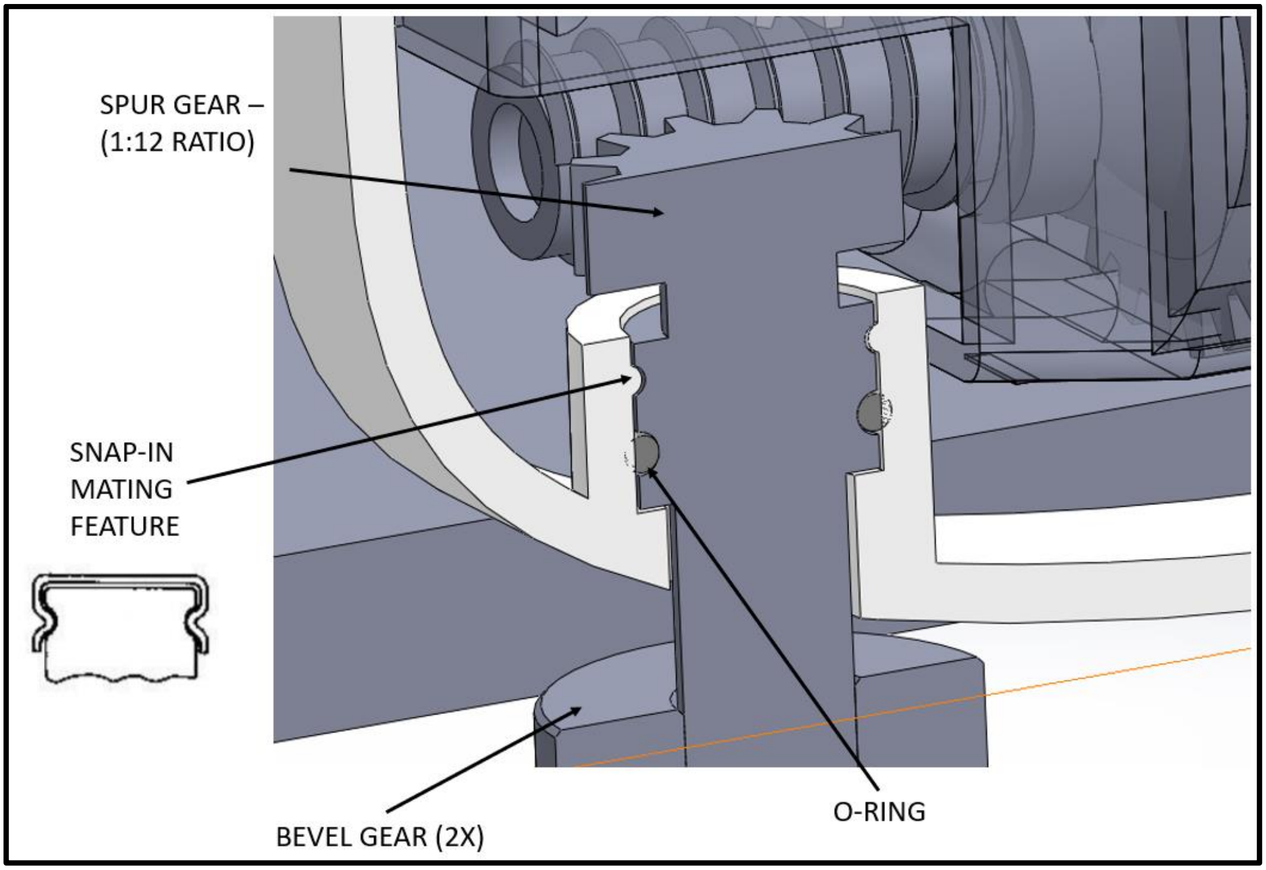


Figure 15: Cross section of new gear design secured in place in component COVER B

Since the new gear will be rotating on an axis that is orientated 90 degrees from the rear axle two bevel gears are utilized to change the axis of rotation. One is secured to the shaft of the new gear on the outside of the gearbox housing and the other is secured to the rear axle of the sprinkler. These gears will require some fine adjustment in order to mate properly and also need to be secured to each component permanently. To accomplish this a small nail is driven through the collar of the bevel gear and through the shaft that it is connected to.

The new cover will have a more complicated mold because the boss and hole through the bottom for the new gear addition will be opposite of the mold pull direction. The way that this will be accomplished is by using a side action pin that will be input into the mold after the two mold halves are placed together. Following that assembly, the part can be injected molded. Since there is a ridge for the snap-in feature for the drive gear there will be resistance when removing the pin. That type of feature is called a bump off [7]. Although this makes the mold design slightly more expensive and adds another part it does not add significantly more mold setup time. A similar mold will have to be used for the new drive gear with a side action to create the proper geometry. These costs of more complicated and intricate molds are accounted for in the cost analysis detailed is Section 9.

6.2 Wheels and Axles

A couple more key components for the traveling sprinkler include the front wheel assembly as well as the rear shaft and wheels. The front wheel assembly's main purpose is to guide the traveling sprinkler across the yard by tracking the hose that is laid out by the user in the desired pattern. The rear shaft and wheel are there in order to drive the entire product using gear systems in conjunction with the water pressure coming from the hose. Figure 16 below displays the front wheel assembly. This includes the snap fit mount, clevis bracket, and front wheels. It is wide enough and tall enough to fit on any regular sized hose and use it as a track.

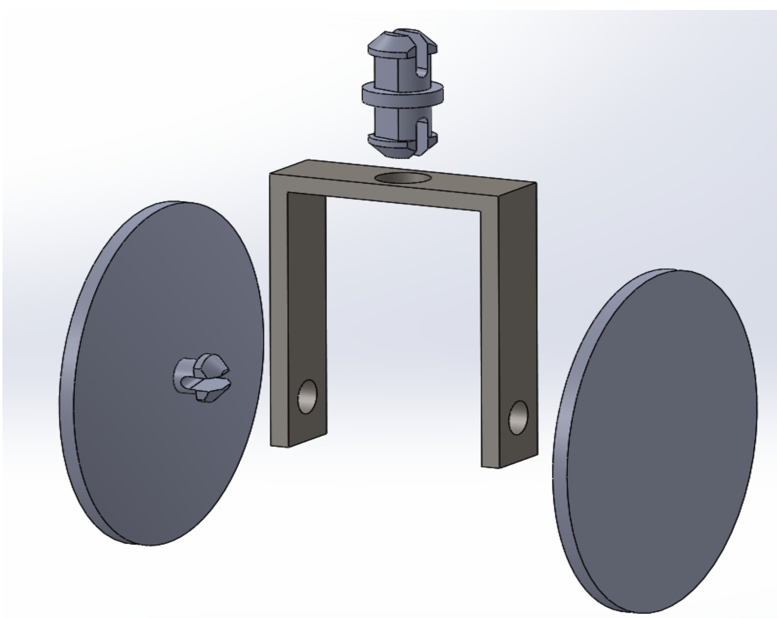


Figure 16: Displays the front wheel assembly exploded view. Both the wheels, clevis bracket, and the bracket mount snap in.

The front wheels provided a lot of room for DFM and DFA analysis. With the front wheels we looked at a design that seemed fairly simple. This assembly includes a bracket, wheels, and snap fit to connect it to the base of the sprinkler. The clevis bracket was chosen to be A36 steel metal for simplicity and because if it were plastic it would not have been able to handle the forces it would have needed to in order to guide the sprinkler. Along with meeting the specifications, we decided to leave the bracket as a separate piece and therefore lean more towards the DFM instead of DFA. This led us to using a clevis bracket that connects to the two wheels. After thinking about the clevis bracket, we needed to think about how we are going to connect the wheels to the bracket and then the bracket to the base. Initially we had an aluminum rod as an axle, but decided to just include snap fits in the front wheels to reduce the number of parts and therefore make the assembly easier and more intuitive. This choice leans more toward the DFA side and making the assembly easier vs the manufacturing process. We also decided to make an injection molded snap fit for mounting the clevis bracket to the base. These decisions were made in part too because we have a ton of injection molded parts and so in terms of design for manufacturing, we are using similar processes which reduces total cost per unit, all while decreasing the number of parts and making the assembly simpler. Following the front wheel assembly comes the rear wheels and axle. Figure 17 below display these models that were designed and created.

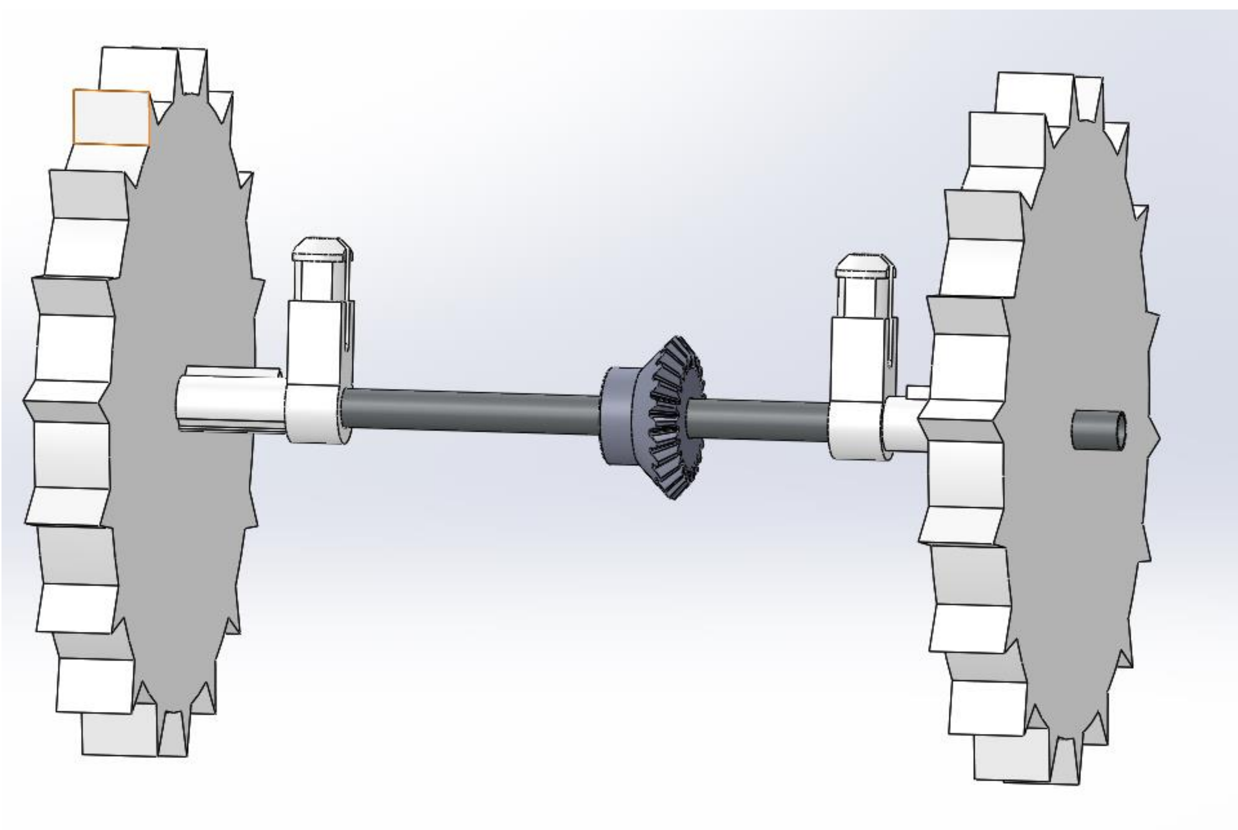


Figure 17: Displays the rear wheel assembly including an extruded aluminum shaft, snap connections to the base, a bevel gear, and the rear wheel.

The rear wheel assembly is very critical to this design. This is what provides the force against the ground in order to move the sprinkler across the yard. The wheels have ridges to allow for more traction and essentially a greater coefficient of friction with the ground. These will also be injection molded in order to use similar manufacturing methods. Initially the wheel and the spacer that protrudes from the wheel, were designed separate parts, but due to wanting to reduce the number of parts and changing from a solid rod to a tube, we ended up combining these two into one part. This makes it a more complicated part to make, leaning towards DFM, but still doesn't require anything extra such as a side action, so it was a good choice made. Along the combining the spacer and rear wheel, a cutout was designed to allow the assembler to easily know where to punch the nail into the wheel and allow it to be driven. This will save time during the assembly process and therefore was a good design from the point of DFA. Initially the rear axle was design to be a rod, but was changed to be a tube in order to be similar to the other aluminum part we have in our product, the main water pipe, as well as so that we can actually punch that nail through it and get a driven wheel. Figure 18 below displays the model for the rear wheel, including the spacer with the guiding notch.

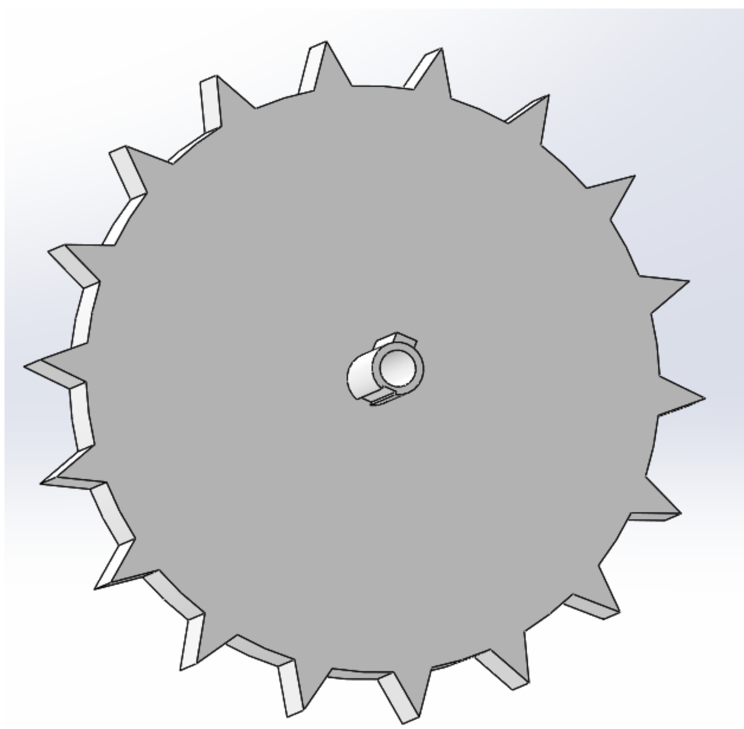


Figure 18: Displays the rear wheel spacer section where the nail will be installed

6.3 Base Part

The base of the sprinkler, GCI-001 (formerly PLA-014) was completely redesigned from the existing oscillating sprinkler design. When designing the new base, we had three primary design specifications. The first design was that the base should mate all subassemblies of the mobile sprinkler together, including the front wheel, rear wheel axle, drivetrain, and main water pipe. The second design specification was to make the base part heavy enough to meet the weight requirements laid out in section 4.1, specifically that the entire mobile sprinkler assembly, without water, should weigh at least 2.9 lbs. The final specification was that the base should be made using an inexpensive manufacturing process in order to meet our ultimate design goal to keep the sales price of our mobile sprinkler below $25.

When designing the sprinkler base, the first step was to determine the manufacturing process the base would be made out of. It was known that the base would have to be roughly 12” by 5” in size, with a thickness of about a quarter of an inch or less. The total weight of the assembly also needed to be about 2.9 lbs, and the weight of all other plastic parts was estimated to be only a little over a pound total. Therefore, the base itself needed to weight roughly 2 pounds in order to meet our weight requirement so that the mobile sprinkler could pull the hose. Knowing these size and weight requirements, plastic injection molding was quickly eliminated as a possible manufacturing method, since plastic is not nearly dense enough. However, even though the plate needed to be heavy, it did not need to be particularly strong, only needing to support a few pounds at most. Therefore, we decided that casting would likely be the best manufacturing method for the base since it is typically an inexpensive manufacturing process yet incorporates dense metals.

Once we decided to cast the base, we determined the exact casting method and material. At first die casting was considered due to the anticipated large quantity of production, however the metals that can be cast with die casting, such as Aluminum, Magnesium, or Zinc, are not dense enough to meet our weight requirements in a 12” by 5” by ¼” plate. Therefore, we opted to sand cast the base using gray cast iron. Since we were using sand casting, we wanted to keep the base plate geometry relatively simple with loose tolerances. We detail the process selection for the base more in depth in section 8.2.

In total the base needs to connect to 4 parts: the end of the main water pipe (ALU-001), the covers of the gear drivetrain (PLA-055 and PLA-056) , the top of the clevis bracket connected to the front wheel (A36-001), and the rear shaft connected to the back wheels (ALU-002). There also needs to be a through hole near the back of the cover to give room for the rear axle drive gear (PLA-031) and bevel gear (PLA-030) to drop through and connect to the rear shaft. All 4 connections are made with plastic snap in features. 3 new injection molded snap fit parts were designed (PLA-015, PLA-016, and PLA-025) to attach to the rear axle, main water pipe, and clevis bracket respectively. Furthermore, the designs of Covers A and B were redesigned to sit flat on the top of the base, and bosses were added that snap into a hole on the base. One of the new snap fit parts, PLA-016 which connects to the front of the main water pipe, is displayed below in Figure 19.

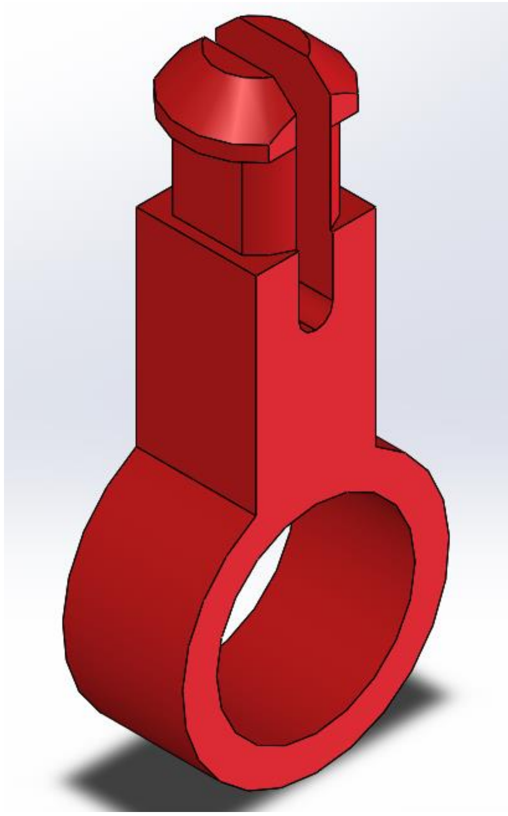


Figure 19: PLA-016 fits around the main water pipe and snaps into the sprinkler base

The final sprinkler base (GCI-001) with the holes for the snap in fits and through hole for the rear axle drive gear and bevel gear, is shown below in Figure 20.

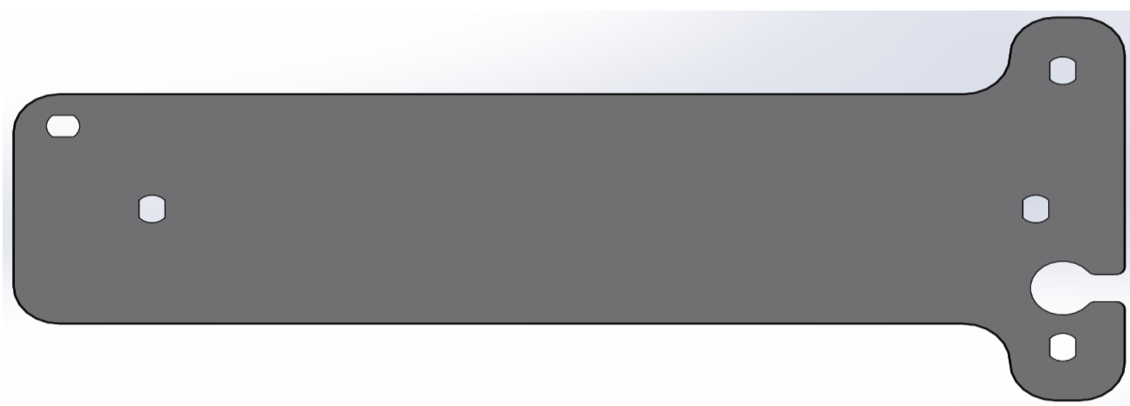


Figure 20: GCI-001 Sprinkler Base CAD model

A slot was added to the right of the circular through hole for the rear axle drive gear and bevel gear (in the lower right of the picture). This is to allow room to install a rivet during assembly to connect the rear axle drive gear (PLA-031) to the bevel gear (PLA-030) to lock rotation between the two pieces. Finally, a 3º draft was added along all edges perpendicular to the view plane in Figure 20 to allow for easy removal of the base part after casting. The thickness of the base was chosen to be ¼", which was the maximum thickness possible without interference between the base and the rear axle. The final weight of the base plate was 2.4 lbs, which made the total weight of the sprinkler assembly 3.5 pounds, which exceeds the minimum 2.9 lbs weight requirement laid out in section 4.1. The cost estimate to manufacture the base is $2.72, and is discussed later on in section 9.

6.4 Shut-Off Ball Valve

The ball valve along with the stopper are used as a stopping mechanism for the mobile sprinkler. The ball valve includes parts such as ball (PLA-036), ball valve pipe (PLA-038), flat head 4-40 screw, 4-40 nut, stopper (PLA-037), and a handle (PLA-035). A ball valve is a form of quarter-turn valve which uses a hollow, perforated and pivoting ball to control flow through it. It is open when the ball's hole is in line with the flow and closed when it is pivoted 90-degrees by the valve handle. The assembly models developed are shown below in Figure 21.

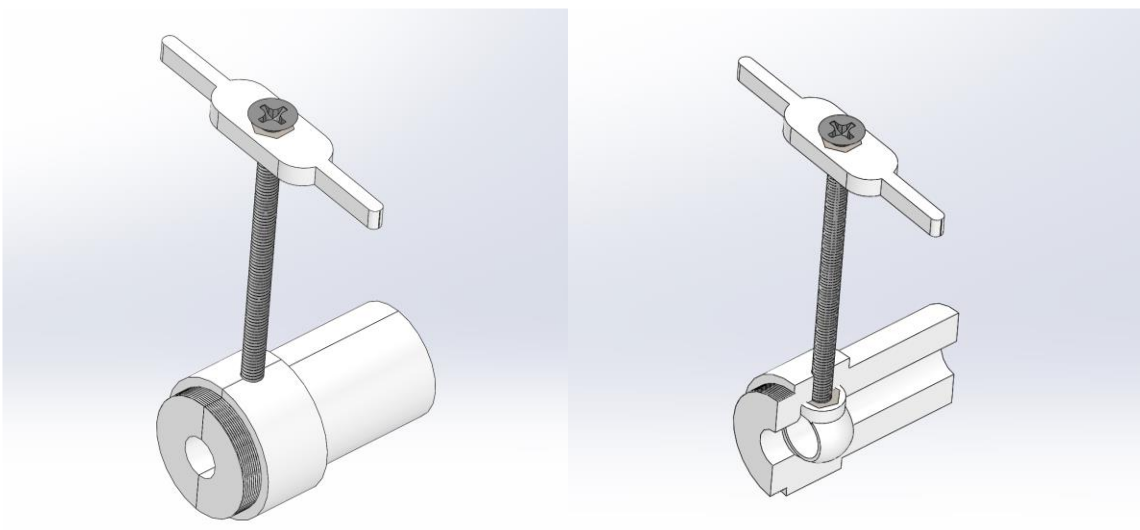


Figure 21: CAD models of shut-off ball valve assembly

Finding a way to position the ball valve inside the pipe during assembly proved very challenging. After some additional research, it was decided that the pipe should be injection molded around an already finished ball valve. Therefore, once the pipe is molded, the ball valve will already be positioned correctly within the pipe. During molding, the ball will be held in place using a mandrel. The ball valve and pipe will need to be made out of different, incompatible materials, and the ball material will need to have a higher melting temperature than the material for the pipe so that the materials do not mix during the molding of the pipe. Therefore, the ball will be injection molded out of Nylon, which has a melting temperature of 260^{o} F, and the pipe will be molded out of ABS, which has a melting temperature of 220^o F [8]. Threads would be added to the outer part of the Ball-Valve which would be screwed to the cover. The threads can be seen on the ball valve which attach on to the Cover.

6.5 Stopper

The stopper is used in conjunction with the ball valve to stop the water flow into the sprinkler. It can be placed anywhere along the path of the hose as a stopping point. The stopper has a groove so that the hose can stay on top of it and its weight can hold the stopper down in its place. This serves an additional purpose of not using additional parts to hold the stopper down. The stopper passes underneath the front two wheel and does the extension in the stopper moves the handle of the shut-off valve which in turn moves the ball in the valve and stops the water flow. A draft of 2 degrees is added along the length of the stopper to allow the plastic piece to be ejected after being molded. The CAD model that was developed is shown below in Figure 22.

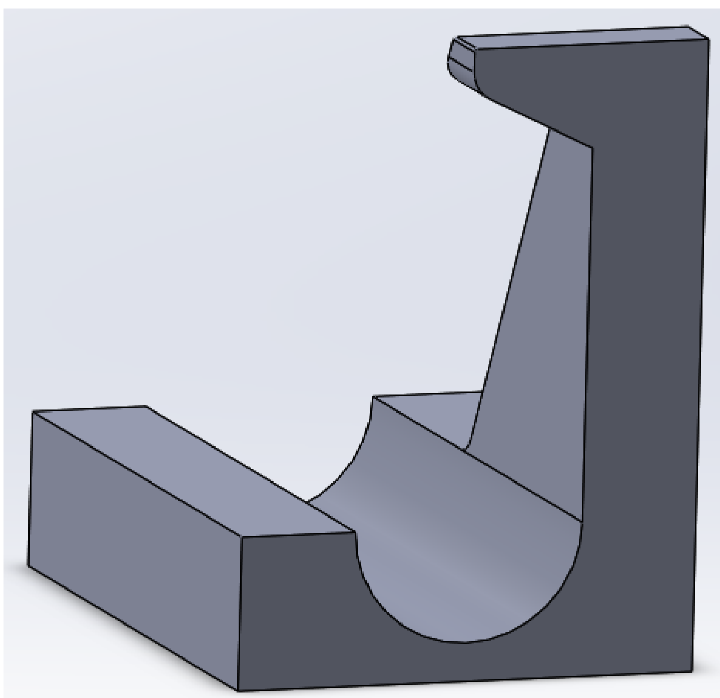


Figure 22: CAD model of stopper design used to rotate and shut off input valve

7 Bill of Materials

Our completed Bill of Materials (BOM) is shown below in Table 2. This BOM details the quantity, cost, and manufacturing method or source for all 42 unique parts in our final assembly, including 36 non-standard parts. Our method of cost estimate for all non-standard parts will be detailed in section 9 of this report.

Table 2: Bill of Materials for Novel Mobile Sprinkler Design

#	Part #	Qty	Name	Material	Indiv. Cost	Total Cost	Source/Mfg. Method
1	A36-001	1	CLEVIS BRACKET	A36 STEEL	$0.35	$0.35	SHEET METAL
2	ALU-001	1	MAIN WATER PIPE	ALUMINUM	$1.13	$1.13	STOCK
3	ALU-002	1	REAR AXLE	ASTM A513 TYPE 5	$0.46	$0.46	SHEET METAL AUTOMATION
4	GCI-001	1	BASE	GRAY CAST IRON	$2.72	$2.72	SAND CAST
5	PLA-001	1	DIAL BUFFER	NYLON 101	$0.24	$0.24	INJEC. MOLD
6	PLA-002	1	DRIVE LINKAGE	ABS	$0.29	$0.29	INJEC. MOLD
7	PLA-003	1	HANDLE CLIP	ABS	$0.32	$0.32	INJEC. MOLD
8	PLA-004	1	DIAL FIXTURE	ABS	$0.35	$0.35	INJEC. MOLD
9	PLA-005	1	CROWN	NYLON 101	$0.24	$0.24	INJEC. MOLD
10	PLA-006	1	CHAMFERED RING	NYLON 101	$0.31	$0.31	INJEC. MOLD
11	PLA-007	1	WATER PRESSURE TURBINE	NYLON 101	$0.38	$0.38	INJEC. MOLD
12	PLA-008	1	SPRINKLER TUBE SCREW	ABS	$0.32	$0.32	INJEC. MOLD
13	PLA-009	15	NOZZLE	ABS	$0.02	$0.27	INJEC. MOLD
14	PLA-010	1	TURBINE SHAFT	NYLON 101	$0.24	$0.24	INJEC. MOLD
15	PLA-011	1	TURBINE COVER	NYLON 101	$0.34	$0.34	INJEC. MOLD
16	PLA-012	1	GEAR SHAFT	NYLON 101	$0.34	$0.34	INJEC. MOLD

#	Part #	Qty	Name	Material	Indiv. Cost	Total Cost	Source/Mfg. Method
17	PLA-013	1	DIAL	NYLON 101	$0.25	$0.25	INJEC. MOLD
18	PLA-015	2	REAR AXLE MOUNT	NYLON 101	$0.24	$0.48	INJEC. MOLD
19	PLA-016	1	WATER PIPE MOUNT	ABS	$0.24	$0.24	INJEC. MOLD
20	PLA-020	2	FRONT WHEEL	NYLON 101	$0.37	$0.74	INJEC. MOLD
21	PLA-025	1	FRONT BRACKET MOUNT	NYLON 101	$0.24	$0.24	INJEC. MOLD
22	PLA-028	2	REAR WHEEL	ABS	$0.62	$1.24	INJEC. MOLD
23	PLA-030	2	BEVEL GEAR	NYLON 101	$0.33	$0.66	INJEC. MOLD
24	PLA-031	1	REAR AXLE DRIVE GEAR	ABS	$0.52	$0.52	INJEC. MOLD
25	PLA-035	1	BALL VALVE HANDLE	ABS	$0.24	$0.24	INJEC. MOLD
26	PLA-036	1	BALL	NYLON 101	$0.46	$0.46	INJEC. MOLD
27	PLA-037	1	STOPPER	ABS	$0.40	$0.40	INJEC. MOLD
28	PLA-038	1	BALL VALVE PIPE	ABS	$1.19	$1.19	INJEC. MOLD
29	PLA-051	1	GEAR DRIVE	ABS	$0.34	$0.34	INJEC. MOLD
30	PLA-052	1	COMPOSITE GEAR SHAFT	NYLON 101	$0.34	$0.34	INJEC. MOLD
31	PLA-053	1	INSIDE GEAR	ABS	$0.34	$0.34	INJEC. MOLD
32	PLA-054	1	KNOB	ABS	$0.37	$0.37	INJEC. MOLD
33	PLA-055	1	COVER A	ABS	$0.41	$0.41	INJEC. MOLD
34	PLA-056	1	COVER B	ABS	$0.41	$0.41	INJEC. MOLD
35	RUB-001	1	SQUARE RING AND FILTER	NITRILE	$0.40	$0.40	INJEC. MOLD
36	RUB-002	1	SQUARE RING	NITRILE	$0.40	$0.40	INJEC. MOLD

#	Part #	Qty	Name	Material	Indiv. Cost	Total Cost	Source/Mfg. Method
37	90480A005	2	HEX NUT, 4-40 THREAD SIZE	ZINC-PLATED STEEL	$0.01	$0.02	MCMASTER CARR
38	91771A120	1	4-40, 2" LONG, 18-8 PHILLIPS FLAT HEAD.	STAINLESS STEEL	$0.11	$0.11	MCMASTER CARR
39	91772a238	1	10-24, 1/4" LONG, PHILLIPS PAN HEAD.	STAINLESS STEEL	$0.09	$0.09	MCMASTER CARR
40	9452K190	1	O-RING 5/16" ID	BUNA-N RUBBER	$0.04	$0.04	BUNA-N
41	9452K250	1	O-RING 9/16" ID	BUNA-N RUBBER	$0.04	$0.04	BUNA-N
42	97828A634	5	STEEL FINISHING NAILS, ⅞" LONG	STEEL	$0.01	$0.05	MCMASTER CARR
				Total Cost:	**$18.30**		

8 Product Manufacturing

8.1 Materials Selection

8.1.1 GCI-001 Base

The material selection for the mobile sprinkler base was largely determined by the minimum weight that was calculated to react against the force required to drag the hose throughout the yard. This requirement allowed us to narrow down our choices to materials with higher densities. Also, the stiffness of the base needed to be considered so that all the other sprinkler components can be rigidly mounted to it. This drove us to use the Modulus vs. Density Ashby chart shown below in Figure 23 to determine a proper material. Since the density of the part is of equal importance to the stiffness the E/ρ guide curve was used in the selection. As can be seen in the figure the Ashby chart observations show that most metals can be used to fulfill the requirements. If we also consider the production energy then something like cast iron would be better than higher strength steels. Using that information along with the process selection analysis in Section 8.2, the material for the base was determined to be cast iron.

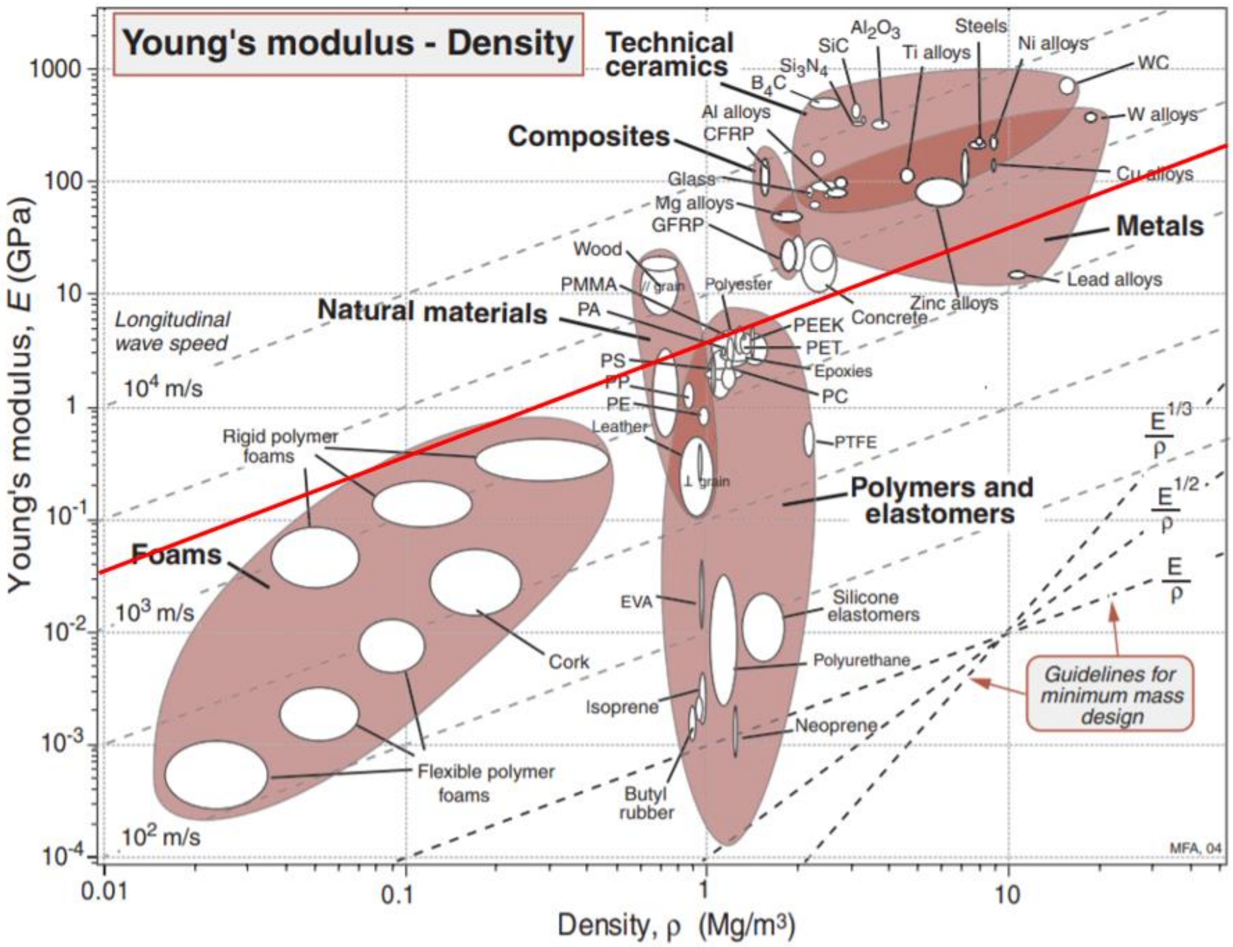


Figure 23: Ashby Chart used for the sprinkler base material selection

8.1.2 A36-001 Clevis Bracket

The clevis bracket is what connects the front wheels to the base plate of the traveling sprinkler. It will be taking on the forces from the hose that is guiding the sprinkler, so in order for this to work it needed to be a strong enough material. Looking at Figure 24 below, we see that the material for this bracket needs to fall above the red line. Foams, metals, ceramics, composites, and some polymers and elastomers would work for this part. The next step to choosing the material was thinking about cost as well as the method of how we are getting it (manufacturing it or buy off the shelf). We could injection mold this since we are injection molding most other parts, but we also entertained the option of creating a less expensive sheet metal bracket. We chose A36

Steel because it can be bent pretty easily, isn't too expensive to manufacture, and is strong enough for our criteria. We also needed to add more weight to our sprinkler so that it could actually propel itself forward and so that is another reason we chose a metal instead of an injection molded plastic.

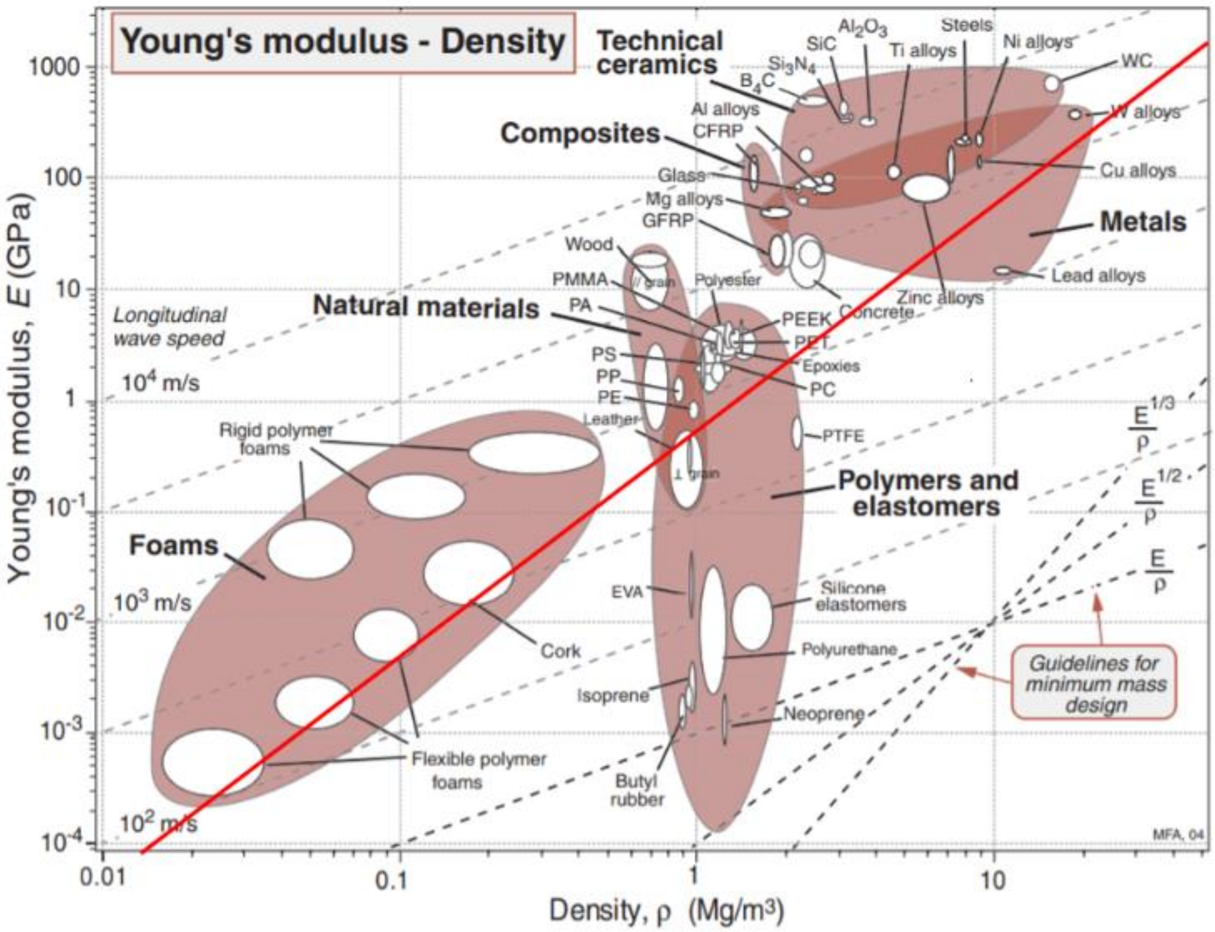


Figure 24: Ashby Chart used for the clevis bracket material selection

Another reason we chose to use a metal was because we wanted the rigidity for this critical part. Without this bracket, the sprinkler does not have the intended traveling function. We wanted to ensure that this part was not brittle, like plastic, and will definitely last the entire intended period of use.

8.1.3 Nylon vs ABS components

Throughout our design we have chosen two main plastics to injection mold. These two plastics are Nylon 101 and ABS. For most components we have chosen ABS because it is common, less expensive, and strong enough. However, for some components we have decided it was better to use nylon because of its property of having a lower coefficient of friction. For any moving plastic parts such as the front wheels, front wheel mount, gears, and rear wheel axle mounts, we chose to use Nylon 101. Mainly for any plastic parts that are moving relative to other parts was our general rule. This will allow for less friction and in turn a more efficient product. Figure 25 below shows coefficient of friction for various plastics along with nylon. Here we see that Nylon 101 has a relatively low coefficient of friction and therefore supports our choice for the moving plastic components.

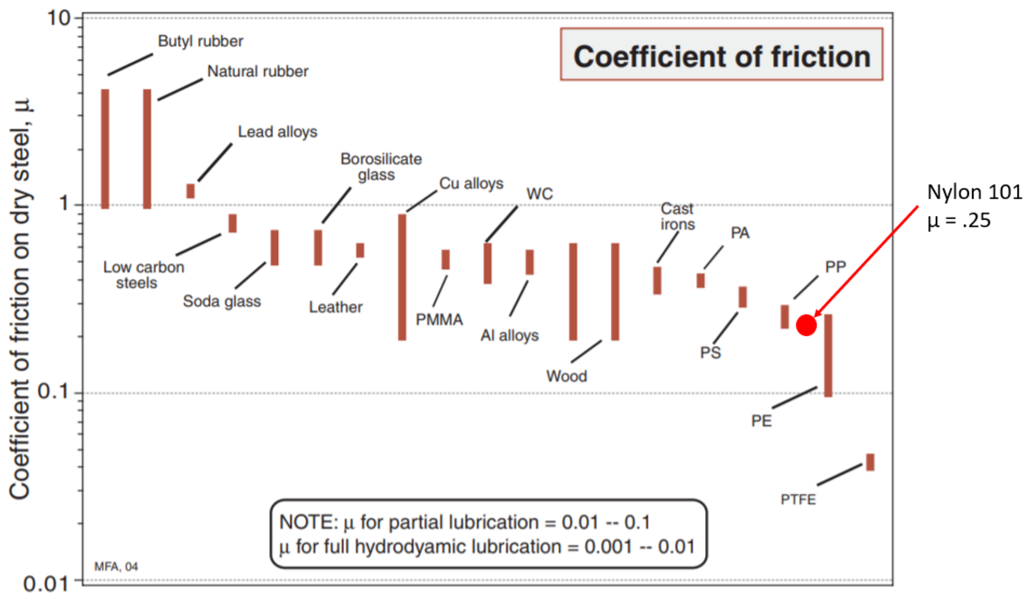


Figure 25: Coefficient of Friction chart of various materials with Nylon 101 labeled

Looking at the figure we see that Nylon 101 has a coefficient of friction equal to 0.25 as compared to ABS which can be as high as 0.46. This is why we used Nylon 101 for moving parts, and ABS for non-moving parts.

8.2 Process Selection

One of the more important new additions to the mobile sprinkler design is the base that holds all the parts together. We calculated early in the design process that we would need added weight to the assembly in order to react against the force required to drag half the length of the hose throughout the yard. Since we were able to make the base a fairly simple part, we decided to manufacture the base component out of a metal material that could give us the added weight we needed. Since the part is fairly simple without any complex shapes or cutouts in the part, we realized the part could either be machined out of plate or could be cast. The machining process would be much more precise, but the design has larger tolerances that could also be accommodated by the casting process. A process selection analysis was then completed to decide on the most economical and efficient process to manufacture the base. The subsequent analysis was completed using charts and figures provided by Professor Dan Riffell [10], and weighing the various processes against the possible material choices as well as our prediction of a batch size of 10,000 units. Once the various processes have been reduced based on part geometry and production number, a cost estimate for each process is completed to finalize the process selection.

The first step in the process is to research the various manufacturing process that are capable of manufacturing several different metal materials. The materials we decided could be the best matches for our design were aluminum, steel, and iron. These are the three most common and inexpensive metal materials that have flexibility in manufacturing processes while also providing us with an added weight that is required. Table 3 below shows a binary look at whether specific processes can or cannot be completed with our chosen materials.

Table 3: Displays the initial screening of the candidate processes for the mobile sprinkler base component

	Aluminum		Steel		Cast Iron		
Manufacturing Process	**Yes or No?**	**Reject?**	**Yes or No?**	**Reject?**	**Yes or No?**	**Reject?**	**Rejection Reason**
Sand Casting	Y		Y		Y		
Investment Casting	Y		Y		Y	R	Not common for cast iron
Die Casting	Y		N		N		
Injection Molding	N		N		N		
Impact Extrusion	Y		Y		N		
Hot Extrusion	Y		Y	R	N		Not common for steel
Closed Die Forging	Y		Y		N		
Machining	Y		Y		Y		
Sheet Metal	Y		Y		N		

Based on our initial research and results of comparing the various processes against the material choices we made, we can narrow down the processes we think are the most valid for each material. The decision of which processes to move forward with in the analysis are swayed also by whether the process is possible over the spectrum of material choices. Based on our initial research of processes and seeing what processes are possible for all three materials, we decided to move forward with sand casting or traditional machining.

The sprinkler base is essentially just a flat plate with some holes and cutouts in the flat part so we know that this simple shape can be manufactured through a traditional machining or casting process. Since the part in question does not have any complex geometry we can move to the next step in the process selection analysis. A method to further narrow down the process selection is to use a ranking system that takes into account other factors in the manufacturing process such as cycle time, process flexibility, material waste, quality, and tooling costs. Table 4 below shows how each factor is ranked on a scale from 1 to 5 and Table 5 shows the various rankings for casting and machining processes.

Table 4: Displays the rating scale for characteristics of common manufacturing processes

Rating	Cycle Time	Flexibility	Material Utilization	Quality	Equipment Tooling Costs
1	>15 min	Changeover very difficult	Waste >100% of finished part	Poor quality	High machine and tooling costs
2	5 to 15 min	Slow changeover	Waste 50 to 100%	Average quality	Tooling and machines costly
3	1 to 5 min	Avg changeover and setup time	Waste 10 to 50%	Average to good quality	Tooling and machines relatively inexpensive
4	20 s to 1 min	Fast changeover	Waste < 10% finished part	Good to excellent	Tooling costs low
5	<20 s	No setup time	No appreciable waste	Excellent quality	Equip. and tooling very low

Rating scale: 1, poorest; 5, best

Table 5: Displays the rating of characteristics of the common manufacturing processes in order to further make our decision

Process	Shape	Cycle Time	Flexibility	Material Utilization	Quality	Equipment Tooling Costs	Handbook Reference
Casting							
Sand casting	3-D	2	5	2	2	1	AHB, vol. 15, p. 523
Pressure die casting	3-D solid	5	1	4	2	1	AHB, vol. 15, p. 713
Machining							
Single-point cutting	3-D	2	5	1	5	5	AHB, vol. 16
Multiple-point cutting	3-D	3	5	1	5	4	AHB, vol. 16
Grinding	3-D	2	5	1	5	4	AHB, vol. 16, p. 421

Once the manufacturing processes in question have been ranked for the various important factors, the columns can be totaled. As the above table shows the total for sand casting is 13 and the 18. This ranking system shows that machining could possibly be a more overall efficient process but there are still factors such as mass, thickness, and cost that must be assessed. Guidelines based on the mass of the part exist in the form of tables that helped us assess how well-suited each process is based on our mass and thickness. These figures are shown below in Figure 26 and Figure 27.

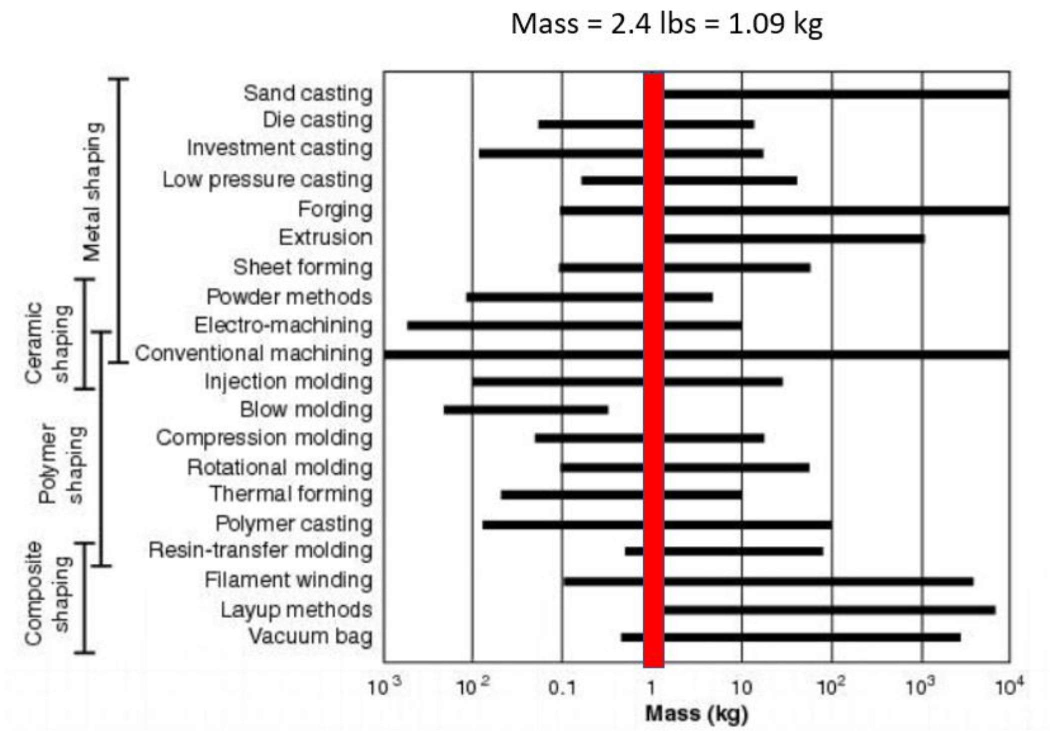


Figure 26: Displays the what process should be used when dealing with certain masses in manufacturing

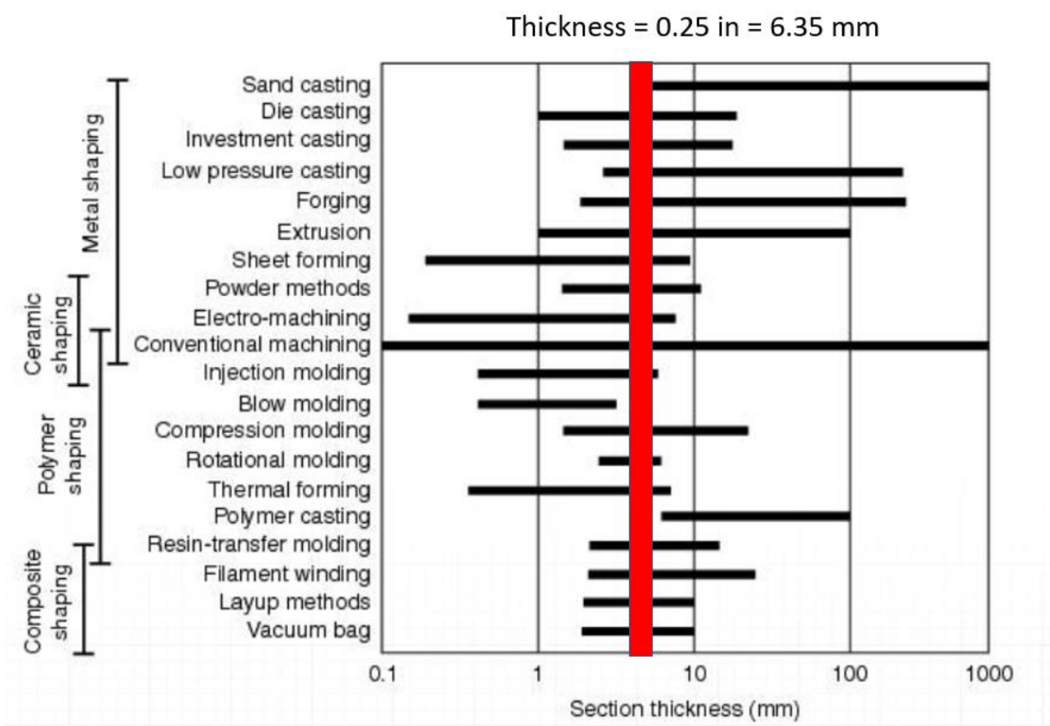


Figure 27: Displays the optimal ranges for certain thicknesses of material being manufactured

The above tables have shown that conventional machining as well as various casting processes are still within the boundaries of our base design. However, the sand-casting process is on the ragged edge of each of the base parameters, so it showed us that we may need to choose a different casting process if we decide to go that route instead of conventional machining. The final part of the analysis we conducted to finally land on a casting choice was to compare the valid processes against our predicted batch size of 10,000 units. Again, a chart can be referenced to aid in this decision shown in Figure 28 below. It is clear based on the figure that with our predicted batch size conventional machining and sand casting are typically not used for that many units. The process that makes the most sense based on batch size would be the low-pressure casting but since the conventional machining is very close to this batch size, we decided to include it in the cost analysis.

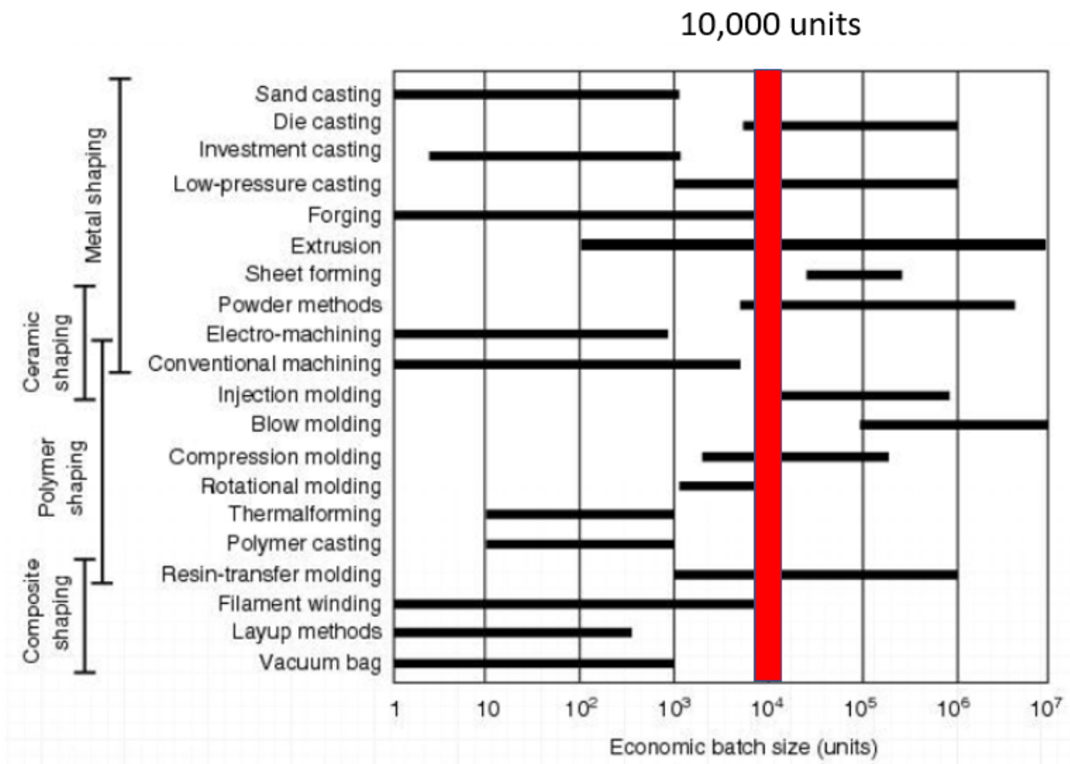


Figure 28: Displays economical batch sizes for the different manufacturing methods

We have narrowed down or process selection for the sprinkler base down to two different choices: conventional machining and low-pressure casting. The final important step in the process is to determine an estimated cost of the part for each process. This will be an easy and quantitative way to make a decision on the best process to move forward. It should be noted though that we are essentially at the maximum recommended batch size for machining so if the batch size were to increase significantly are revisit to the process selection should be completed. The cost analysis which gives us our final decision is shown below in Table 6 which resulted in us choosing low-pressure casting to manufacture the mobile sprinkler base.

Table 6: Displays the cost estimates of the conventional machining and casting manufacturing processes for the sprinkler base

	GCI-001	Machining		Casting	
Material Cost and OME Calc	Weight of Part (lbs)	2.4	2.4	2.4	2.4
	Material	Steel	Cast Iron	Steel	Cast Iron
	Material cost per pound	$0.39	$0.64	$0.39	$0.64
	Nominal Material Cost	$0.94	$1.55	$0.94	$1.54
	Scrap Fraction	0.3	0.3	0.05	0.05
OME Calc Results	Material Cost (Cm)	$1.35	$2.21	$0.99	$1.62
	Total Est. Mfg Cost	$4.04	$6.62	$2.97	$4.85
	Est. Sale Price	$12.11	$19.87	$8.92	$14.55
Labor Cost Calc	Wages Cost per Hour	$20	$20	$20	$20
	Units produced per hour	100	100	100	100
	Labor Cost (Cl)	$0.20	$0.20	$0.20	$0.20
Tooling Cost	Cost of Making Tooling	$3,000	$3,000	$5,000	$2,000
	# parts in production run	10000	10000	10000	10000
	tooling wear factor	1	1	1	1
	Tooling Cost (Ct)	$0.30	$0.30	$0.50	$0.20
Equipment Cost	capital equipment cost	$100,000	$100,000	$100,000	$20,000
	load factor	0.05	0.05	0.05	0.05
	capital write-off time (years)	5	5	5	5
	capital write-off time (hours)	43830	43830	43830	43830
	equip sharing fraction	1	1	1	1
	Equip Cost (Ce)	$0.46	$0.46	$0.46	$0.09
Overhead cost	overhead hourly rate ($/hr)	$60.00	$60.00	$60.00	$60.00
	Overhead Cost (Coh)	$0.60	$0.60	$0.60	$0.60
	FINAL UNIT COST EST. ($ per unit)	$2.90	$3.76	$2.75	$2.71

8.3 Design for Manufacturing Analysis

There were many design decisions made on the new components to the mobile sprinkler that were focused on making the assembly process easier. We felt that since most of the parts are inexpensive, injection molded plastic parts that the assembly process was an area in which we could eliminate waste. Whenever possible we also made decisions that made the individual part manufacture less expensive as well. A significant design decision by the team that utilized Design for Manufacturing (DFM) principles was to use injection molded parts wherever possible. We decided to manufacture all parts that needed a low coefficient of friction, such as drive gears, with Nylon 101 and all other parts out of ABS plastic. All these plastic parts minimized the material usage as much as possible because our cost analysis shows that the part mass is a major driver in overall cost.

Design decisions that helped to improve the assembly time also greatly reduced the manufacturing costs of the components themselves as well. Our decision to use nails to lock our wheel hubs and bevel gears in place allowed the rear axle to simply be an aluminum tube cut to length. Prior to that decision the rear axle was going to have to have flats at each end that also were threaded in order to capture a nut that locked the wheels in place.

Another example of a component that utilizes DFM in order to reduce part cost is the mobile sprinkler base. The flat geometry was chosen to minimize any need for a complex mold or complex geometry that makes handling more difficult. The flat design also allows for great packing factor during manufacturing as well as during shipment and storage.

9 Cost and Economic Analysis

To determine the cost to make and selling price of our novel mobile sprinkler, we performed a cost estimate on all 36 of our non-standard part. Prices for our 6 standard parts such as fasteners or O-rings were instead estimated using the price listed on McMaster.

Of our 36 non-standard parts, 30 are made out of plastic, including 17 ABS parts and 13 Nylon parts. All 30 of these plastic parts will be made using injection molding. To estimate the material cost, we entered the weight of each individual part and looked up the average price per pound of ABS and Nylon. We assumed 5% of material is wasted during the injection molding process. To estimate labor, the hourly pay rate was estimated to be $20, with an overhead rate of $60 per hour.. We estimated that 500 parts could be made per hour, except in the case of the very small nozzle parts, where we estimate 7,500 can be made per hour. The entire production run was assumed to produce 10,000 mobile sprinklers, as opposed to a production run of 50,000 used in our previous cost estimate of the oscillating sprinkler design [1]. The production rate was lowered because it is thought that the mobile sprinklers will sell at a slower rate than oscillating sprinklers, and less mobile sprinklers can be stored in inventory due to their larger size.

Next the mold costs were approximated. For most parts the molds were assumed to cost anywhere from $7,000 to $20,000 depending on the size of the part and feature complexity. However, the rear axle drive gear (PLA-031) and ball for the ball valve (PLA-036) require molds with side-actions, and therefore the mold prices were assumed to be more expensive, $35,000 for the gear and $30,000 for the ball. Finally, as discussed earlier in section 6.4, the ball valve pipe

(PLA-038) is molded around the already finished ball. The mechanisms required to place a part inside of an injection mold cavity is estimated to increase the total price of the ball valve pipe mold up to $100,000.

Finally, the equipment costs were approximated for the plastic parts. It was assumed that 2 injection molding machines would be used to make the 17 total ABS parts and 1 injection molding machine would be used to make the 13 Nylon parts. The price of the injection molding machines was estimated to be $500,000 each, with a load factor of one half.

The most expensive individual part in our mobile sprinkler assembly is the base part (GCI-001) cast out of gray cast iron. The base weighs 2.4 lbs., almost ⅔ of the entire weight of the assembly. The price of gray cast iron is estimated to be $0.64 per pound, and a scrap fraction of 5% is assumed, meaning the material cost of the base is already $1.63. Using sand casting, it is estimated that about 100 base parts can be made an hour, giving a labor cost of $0.20 per part, and an overhead cost of $0.60 per part. Tooling and equipment costs were more inexpensive in comparison, only $0.20 and $0.09 respectively. This brought the total estimated manufacturing cost of the base plate to $2.72 total, which makes up nearly 15% of the total manufacturing costs for the entire assembly. To verify this cost estimate, the price per part was also approximated on custompartnet.com. The site estimated a sand cast manufacturing cost of $2.43 for a production run of 10,000, which is close to our own $2.72 estimate [9].

Of our other 3 metal parts, the main water pipe (ALU-001) and rear axle (ALU-002) were made from stock extruded pipe. The rear axle requires very few secondary machining operations, and therefore the most expensive component of this part's $0.46 cost is overhead. However, the main water pipe requires additional machining to bend the pipe and punch holes for the nozzles. The labor, tooling, equipment, and overhead costs are therefore more significant for this part, and the total estimated cost to manufacture the main water pipe is $1.13, making it the second most expensive individual part.

The last metal part used in the mobile sprinkler assembly was the clevis bracket (A36-001). This simple part will be manufactured using sheet metal operations, and thus material, labor, and overhead costs are low, with tooling and equipment costs constituting the bulk of this part's estimated $0.35 cost.

A summary table is provided below in Table 7 of our cost estimate for all 36 non-standard parts. The full spreadsheet used in our cost analysis is also provided in appendix section 17.1.

Table 7: Summary of part cost estimates for all non-standard parts

#	Part Number	Part Weight (lbs)	Material Cost	Labor Cost	Tool Cost	Equip. Cost	Overhead Cost	Qty.	Total Cost Est.	Total Sales Price	Break Even Point
1	A36-001	0.0888	$0.04	$0.04	$0.10	$0.05	$0.12	1	$0.35	$0.42	21,000
2	ALU-001	0.1168	$0.09	$0.20	$0.20	$0.05	$0.60	1	$1.13	$1.36	7,000
3	ALU-002	0.0252	$0.02	$0.08	$0.10	$0.02	$0.24	1	$0.46	$0.55	16,000
4	GCI-001	2.4150	$1.63	$0.20	$0.20	$0.09	$0.60	1	$2.72	$3.26	5,000
5	PLA-001	0.0028	$0.00	$0.04	$0.07	$0.004	$0.12	1	$0.24	$0.29	29,000
6	PLA-002	0.0032	$0.004	$0.04	$0.12	$0.005	$0.12	1	$0.29	$0.35	23,000
7	PLA-003	0.0040	$0.01	$0.04	$0.15	$0.005	$0.12	1	$0.32	$0.38	21,000
8	PLA-004	0.0206	$0.03	$0.04	$0.15	$0.005	$0.12	1	$0.35	$0.42	20,000
9	PLA-005	0.0011	$0.002	$0.04	$0.07	$0.004	$0.12	1	$0.24	$0.28	29,000
10	PLA-006	0.0003	$0.001	$0.04	$0.14	$0.004	$0.12	1	$0.31	$0.37	21,000
11	PLA-007	0.0095	$0.02	$0.04	$0.20	$0.004	$0.12	1	$0.38	$0.46	18,000
12	PLA-008	0.0065	$0.01	$0.04	$0.15	$0.005	$0.12	1	$0.32	$0.39	21,000
13	PLA-009	0.0002	$0.0003	$0.00	$0.01	$0.000	$0.01	15	$0.27	$0.32	25,000
14	PLA-010	0.0019	$0.003	$0.04	$0.08	$0.004	$0.12	1	$0.24	$0.29	28,000
15	PLA-011	0.0068	$0.01	$0.04	$0.17	$0.004	$0.12	1	$0.34	$0.41	20,000
16	PLA-012	0.0013	$0.002	$0.04	$0.17	$0.004	$0.12	1	$0.34	$0.41	19,000
17	PLA-013	0.0100	$0.01	$0.04	$0.08	$0.005	$0.12	1	$0.25	$0.30	28,000
18	PLA-015	0.0041	$0.01	$0.04	$0.07	$0.004	$0.12	2	$0.48	$0.58	14,000
19	PLA-016	0.0059	$0.01	$0.04	$0.07	$0.005	$0.12	1	$0.24	$0.29	29,000
20	PLA-020	0.0311	$0.05	$0.04	$0.15	$0.004	$0.12	2	$0.74	$0.88	10,000
21	PLA-025	0.0031	$0.01	$0.04	$0.07	$0.004	$0.12	1	$0.24	$0.29	29,000
22	PLA-028	0.2462	$0.33	$0.04	$0.12	$0.005	$0.12	2	$1.24	$1.49	9,000
23	PLA-030	0.0090	$0.02	$0.04	$0.15	$0.004	$0.12	2	$0.66	$0.79	10,000

#	Part Number	Part Weight (lbs)	Material Cost	Labor Cost	Tool Cost	Equip. Cost	Overhead Cost	Qty.	Total Cost Est.	Total Sales Price	Break Even Point
24	PLA-031	0.0031	$0.00	$0.04	$0.35	$0.005	$0.12	1	$0.52	$0.62	12,000
25	PLA-035	0.0012	$0.002	$0.04	$0.07	$0.005	$0.12	1	$0.24	$0.28	29,000
26	PLA-036	0.0004	$0.001	$0.04	$0.30	$0.004	$0.12	1	$0.46	$0.56	14,000
27	PLA-037	0.0596	$0.08	$0.04	$0.15	$0.005	$0.12	1	$0.40	$0.47	20,000
28	PLA-038	0.0152	$0.02	$0.04	$1.00	$0.005	$0.12	1	$1.19	$1.42	5,000
29	PLA-051	0.0051	$0.01	$0.04	$0.17	$0.005	$0.12	1	$0.34	$0.41	19,000
30	PLA-052	0.0047	$0.01	$0.04	$0.17	$0.004	$0.12	1	$0.34	$0.41	19,000
31	PLA-053	0.0049	$0.01	$0.04	$0.17	$0.005	$0.12	1	$0.34	$0.41	19,000
32	PLA-054	0.0309	$0.04	$0.04	$0.17	$0.005	$0.12	1	$0.37	$0.45	19,000
33	PLA-055	0.0605	$0.08	$0.04	$0.16	$0.005	$0.12	1	$0.41	$0.49	18,000
34	PLA-056	0.0558	$0.08	$0.04	$0.16	$0.005	$0.12	1	$0.41	$0.49	19,000
35	RUB-001	0.0023	$0.003	$0.08	$0.07	$0.01	$0.24	1	$0.40	$0.48	17,000
36	RUB-002	0.0025	$0.004	$0.08	$0.07	$0.01	$0.24	1	$0.40	$0.48	17,000
Total Cost to Make, Total Sales Price, and Maximum Break Even Point with 20% Profit (including 6 non-standard parts)									**$18.30**	**$21.96**	**Max 29,000**

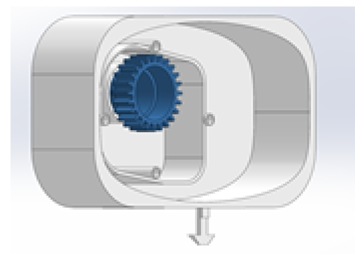
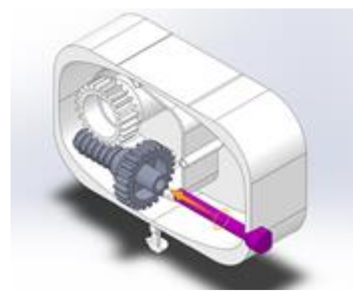
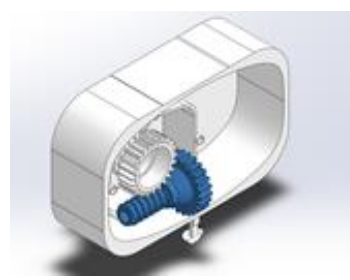
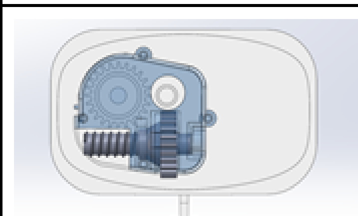
The total cost to manufacture all mobile sprinkler parts is $18.30, including the cost of the 6 standard parts. If we assume a 20% profit margin, we can expect the mobile sprinkler to sell for $21.96. We have therefore met our overall goal for this project, which was to design a mobile sprinkler that can sell for under $25. With a 20% profit margin, the maximum breakeven point for all parts is 29,000. Therefore, in order to sell the mobile sprinkler for about $22, we can expect to have to run at least 3 production runs of 10,000 parts in order to surpass our breakeven point.

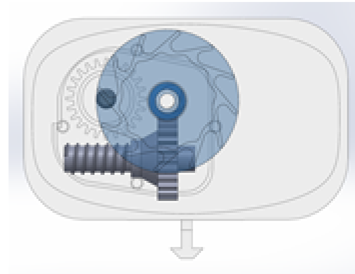
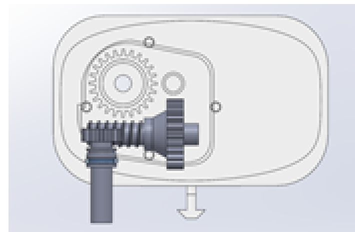
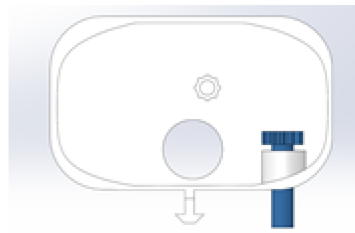
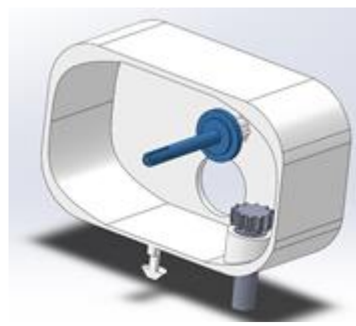
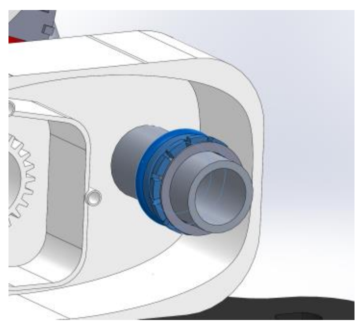
10 Assembly

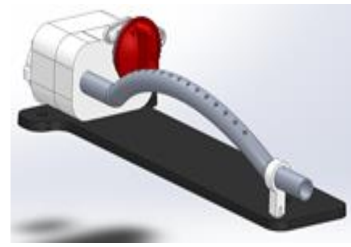
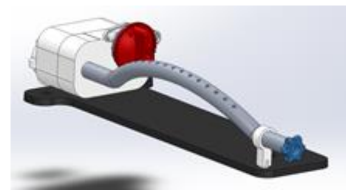
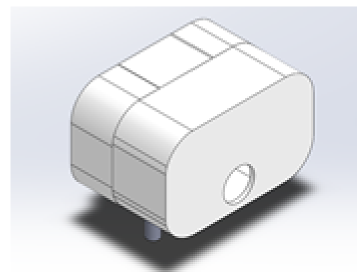
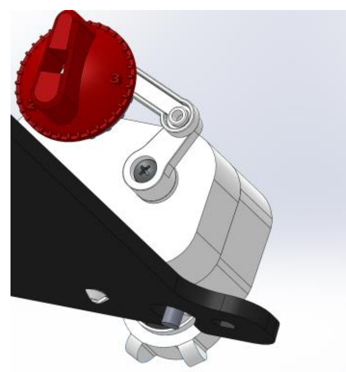
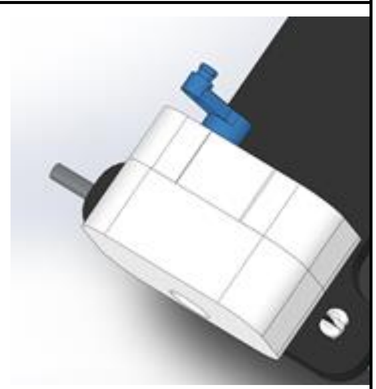
10.1 Assembly Detail

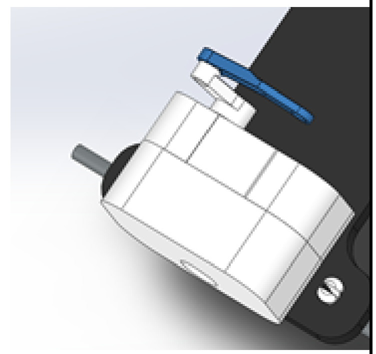
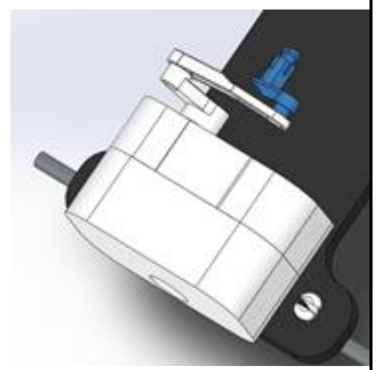
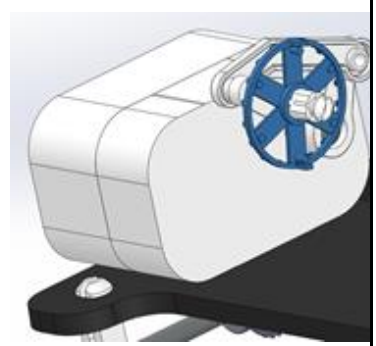
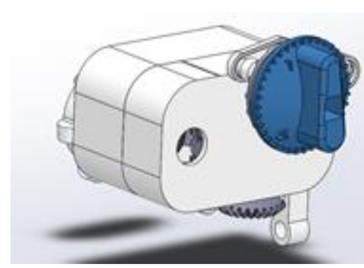
A step-by-step overview of how the mobile sprinkler is assembled is detailed below:

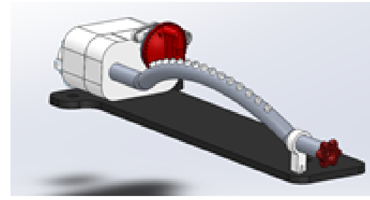
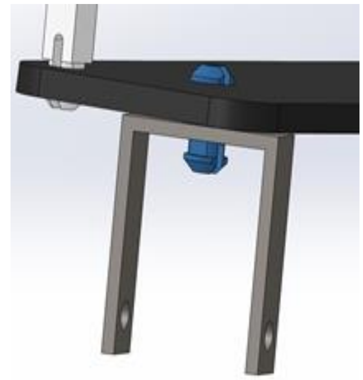
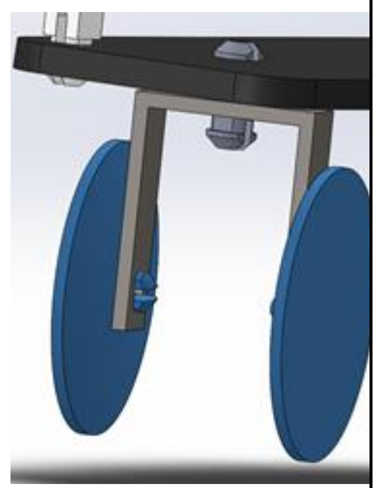
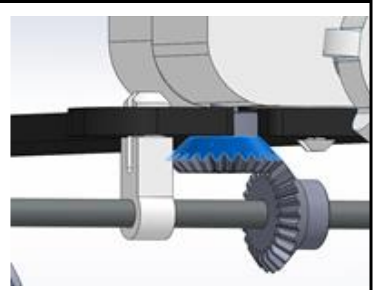
Table 8: Assembly Steps for NP-001 Mobile Sprinkler

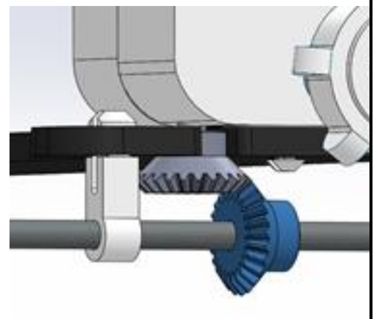
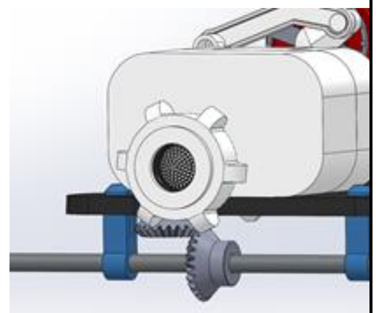
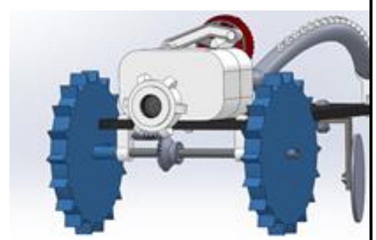
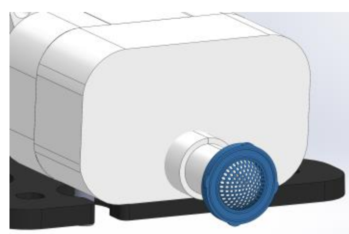
Step 1	Place Inside Gear (PLA-053) into Cover A (PLA-055).	
Step 2	Place the Turbine Shaft (PLA-010) into the slot.	
Step 3	Place the Composite Gear Shaft (PLA-052) in perpendicular direction to the Inside Gear (PLA-053) as shown in the figure.	
Step 4	Place the Turbine cover (PLA-011) and fix it using the screws in the provided slots.	

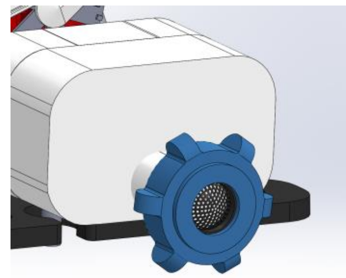
Step 5	Place the Water Pressure Turbine (PLA-007) in the slot in Cover-A (PLA-055).	
Step 6	Place O-Ring (9452K250) on the Axle Gear Drive (PLA-031).	
Step 7	Setup Cover B (PLA-056) and place the Axle Gear Drive (PLA-031) inside the slot.	
Step 8	Place the Turbine Shaft (PLA-010) in the slot available in Cover-B in the orientation shown in the figure.	
Step 9	Slide O-Ring (9452K190), Chamfered Ring (PLA-006), and Crown (PLA-005) onto the Aluminum Pipe (ALU-001).	

Step 10	Fix the Aluminum Pipe (ALU-001) through the Water Pipe Mount (PLA-016).	
Step 11	Keep the Aluminum pipe in place with the help of a Sprinkler Tube Screw (PLA-008).	
Step 12	Join Cover-A and Cover-B using adhesive (INSTATITE cyanoacrylate glue) to form gearbox sub-assembly	
Step 13	Snap fit the gearbox on the Base (GCI-001).	
Step 14	Attach Gear Drive (PLA-051) at the end of Cover A (PLA-055) as shown in the figure.	

Step 15	Snap the Drive linkage (PLA-002) to the Gear Drive (PLA-051).	
Step 16	Snap fit the Handle clip (PLA-003) to the Drive Linkage (PLA-002).	
Step 17	Attach Dial Buffer (PLA-001) to the Handle Clip (PLA-003).	
Step 18	Place the Dial (PLA-013) on the Handle Clip (PLA-003).	

Step 19	Insert 15 Nozzles (PLA-009) into the main water pipe (ALU-001).	
Step 20	Attach the Front Wheel Mount (A36-001) to the base (GCI-001) using the front bracket mount (PLA-025).	
Step 21	Attach the wheel (NYL-020) to the Front Wheel Mount (A36-001) with the help of the snap fit on the wheels.	
Step 22	Attach the Bevel Gear (PLA-030) through the base (GCI-001) to the Rear Axle Drive Gear (PLA-031) using a nail (97828A634).	

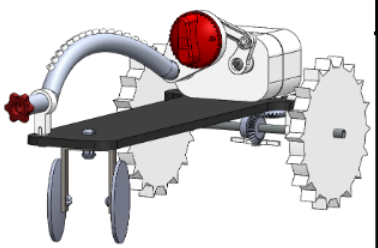
Step 23	Slide the other Bevel Gear (PLA-030) into the Rear Wheel Axle (ALU-002). Use a nail (97828A634) to secure the Bevel Gear to the Axle which enables the Axle to rotate along with the gear.	
Step 24	Attach the Rear Wheel Shaft (ALU-002) the two Rear Axle Mounts (PLA-015).	
Step 25	Attach Rear Wheels (PLA-028) to the Rear Wheel Shaft (ALU-002) and secure with nails (97828A634).	
Step 26	Attach the Ball Valve sub-assembly to the slot in Cover-B (PLA-056).	
Step 27	Attach Filter (RUB-001) to the end of Cover-B (PLA-056).	

Step 28	Attach Square Ring (RUB-002) to the Filter (RUB-001).	
Step 29	Fit the Knob (PLA-054) onto the Square Ring (RUB-002).	

10.2 Design for Assembly Analysis

Design for Assembly (DFA) analysis was conducted on the final mobile sprinkler assembly procedure. Analysis on every component and final DFA metrics are presented in Table 9 below.

Table 9: DFA Analysis on Mobile Sprinkler Design



DFA Analysis Worksheet		Assembly: NP-001 Mobile Sprinkler										Ben, George, Trevor, Kunal									
Part		Complexity		Functional Analysis / Redesign Opportunity				Error Proof		Handling			Insertion				Secondary Operations				
Part #	Part Name	Number of Parts (Np)	Number of Interfaces (Ni)	Theoretical Minimum Part	Part Can Be Standardized (if not already)	Cost (Low/Medium/High)	Practical Minimum Part	Assemble Wrong Part/Omit	Assemble Part Wrong Way	Tangle, Nest, Stick Together	Flexible, Sharp, or Slippery	Pliers or Tweezers Needed	Difficult to Align/ Locate	Holding Down Required	Resistance to Insertion	Obstructed Visibility	Re-orient Workpiece	Screw, Twist, or Rivet	Weld, Solder, or Glue	Paint, Lube, or Heat	Test, Measure or Adjust
A36-001	CLEVIS BRACKET	1	3	0	0	M	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0
ALU-001	MAIN WATER PIPE	1	22	1	0	H	1	0	1	0	1	0	0	1	0	1	1	1	0	0	1
ALU-002	REAR AXLE	1	9	1	0	M	1	0	0	0	1	0	0	1	0	0	1	1	0	0	0
GCI-001	**BASE (BASE PART)**	1	7	1	0	H	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLA-001	DIAL BUFFER	1	2	0	0	L	0	1	1	0	0	0	1	0	0	0	0	1	0	0	1
PLA-002	DRIVE LINKAGE	1	2	0	0	L	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
PLA-003	HANDLE CLIP	1	2	0	1	L	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
PLA-004	DIAL FIXTURE	1	3	0	0	L	1	0	1	0	0	0	1	1	1	0	0	1	0	0	0
PLA-005	CROWN	1	2	0	1	L	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
PLA-006	CHAMFERED RING	1	2	0	1	L	0	1	1	0	0	0	0	0	1	0	0	0	0	0	0
PLA-007	WATER PRESSURE TURBINE	1	4	0	0	L	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
PLA-008	SPRINKLER TUBE SCREW	1	2	0	0	L	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
PLA-009	NOZZLE	15	15	0	0	L	15	0	0	0	0	1	0	1	1	0	0	0	0	0	1
PLA-010	TURBINE SHAFT	1	3	0	0	L	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0
PLA-011	TURBINE COVER	1	1	0	0	L	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0
PLA-012	GEAR SHAFT	1	2	0	0	L	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0
PLA-013	DIAL	1	2	0	1	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLA-015	REAR AXLE MOUNT	2	6	1	0	L	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
PLA-016	WATER PIPE MOUNT	1	2	1	0	L	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
PLA-020	FRONT WHEEL	2	2	1	0	L	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0
PLA-025	FRONT BRACKET MOUNT	1	2	1	1	L	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
PLA-028	REAR WHEEL	2	4	2	2	M	2	0	0	0	1	0	1	0	0	0	0	0	0	0	0
PLA-030	BEVEL GEAR	2	5	0	2	M	2	0	0	0	0	0	1	1	0	0	0	0	0	0	0
PLA-031	REAR AXLE DRIVE GEAR	1	4	0	0	L	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
PLA-035	BALL VALVE HANDLE	1	3	0	0	L	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
PLA-036	BALL	1	3	1	1	L	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLA-037	STOPPER	1	1	1	0	M	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLA-038	BALL VALVE PIPE	1	4	0	1	H	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PLA-051	GEAR DRIVE	1	2	1	0	L	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
PLA-052	COMPOSITE GEAR SHAFT	1	5	1	1	L	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0
PLA-053	INSIDE GEAR	1	2	1	0	L	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0
PLA-054	KNOB	1	1	0	0	L	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0
PLA-055	COVER A	1	6	0	0	M	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0
PLA-056	COVER B	1	5	0	0	M	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0
RUB-001	SQUARE RING AND FILTER	1	2	0	0	L	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
RUB-002	SQUARE RING	1	2	0	0	L	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0
90480A005	HEX NUT, 4-40 THREAD SIZE	2	4	0	0	L	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0
91771A120	4-40, 2" LONG, FLAT HEAD.	1	4	0	0	L	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
91772a238	10-24, 1/4" LONG, PAN HEAD.	1	2	0	0	L	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0
9452K190	O-RING 5/16" ID	1	2	0	0	L	1	1	0	1	1	1	0	0	1	0	0	0	0	0	1
9452K250	O-RING 9/16" ID	1	2	0	0	L	1	1	0	1	1	1	0	0	1	0	0	0	0	0	1
97828A634	STEEL NAILS, ⅞" LONG	5	10	0	0	L	0	0	0	0	1	0	1	1	1	0	1	1	0	0	0
	Totals	65	168	14	12	0	47	13	12	8	9	3	8	8	12	3	7	11	2	0	5
	Design for Assembly Metrics	**104.5**		**21.5%**	←Theor. Effy. Pract. Effy.→		**72.3%**	**1.79**		**1.43**			**2.21**				**1.79**				

In total there are 65 separate parts that have a combined 168 total interactions. This gives a final DFA Complexity Factor of 104.5. The theoretical minimum part count is only 14, giving a theoretical efficiency of 21.5%. The practical minimum part count is 47, giving a practical efficiency of 72.3%.

13 of 65 parts were identified as likely to be omitted, and 12 parts were identified as likely to be assembled the wrong way. Handling of parts is not a large issue in this assembly, as 8 parts could be tangle or stick together, 9 parts are flexible or slippery, and only 3 parts are small enough to require pliers or tweezers to handle.

A total of 8 parts were identified as difficult to align, with 8 parts needing to be held down, and 12 parts having resistance to insertion. Most of these parts are located on the rear axle, such as the rear wheels (PLA-028), bevel gears (PLA-030), and finishing nails (97828A634) used to fix these components. A future improvement to the current assembly would be to modify existing parts to make them self-locating on the rear axle. Only 3 parts have obstructed visibility during assembly.

7 out of 65 parts require reorientation of the work station. 5 parts require further testing or adjusting during assembly. No parts require paint, lubrication, or heat, and only 2 parts require adhesive to be assembled together (Covers A and B, PLA-055 and PLA-056). However, 11 total parts need to be screwed or twisted in.

During the design process of the mobile sprinkler, we attempted to minimize the number of fasteners in the assembly in favor of snap-in features. In total, there are 2 nuts and 7 fasteners in the assembly, including 5 nails. Two of these nails are used to fasten the 2 rear wheels (PLA-028) to the rear axle (ALU-002), two nails are used to fasten the two bevel gears to the rear axle and rear axle drive gear (PLA-031), and one nail is used to fasten the dial fixture (PLA-004) to the main water pipe (ALU-001). The team thought of ways to avoid using these nails, but it was decided that using the nails was the cheaper alternative. In the case of the rear axle, for example, the stock aluminum pipe could have been machined, bent, and crimped to locate the rear wheels and bevel gear. However, nails are a highly inexpensive standard part, and allow us to simplify the features and geometry on many other parts. The primary drawback to using the nails is the labor time required to install them.

11 Future Test Plan

There are several components to the design that would benefit from testing after an initial prototype was designed and manufactured. The first testing we would like to do would be to assess the stability of the assembly while it moves throughout various terrain to see whether the center of gravity is in a low enough position. Many customers that have reviewed different mobile sprinkler designs have complained about the product tipping over while watering. This could be tested fairly easily by measuring various angles and terrain that eventually tip our design over and assess whether those maximum angles are within a reasonable angle for most customers yard undulation.

Another objective to future testing we have would be to test our assumptions on the force required to drag the hose throughout the yard while watering. The coefficient of friction between the hose and the lawn was a major assumption we had to make in our calculations because that data could not be found through research. Design changes driven by this testing would most likely be in the gear ratio of the new added gear to ensure a sufficient torque was applied to the rear axle.

More testing that would be conducted would be to measure the volume of water that gets sprinkled onto the lawn. We had to make an assumption on the velocity the sprinkler travels across the yard to allow for a sufficient watering. It would be valuable to know the whether the average velocity of our design was in the range we desired. Simple tests could be conducted that measure the volume and the drive gear could be designed to provide a different velocity if required.

12 Safety and Human Factors

12.1 Safety

Most of the parts in the assembly are pretty light weight, except for the base which is made of cast iron. This product has many small parts but are enclosed in a cover for the protection of the device as well as preventing any choking hazard in small children. Apart from that, there are some minor safety considerations that were taken in the manufacturing of the parts. The edges of the base part of the assembly should not be sharp so that it does not cause any harm to the user while using it or the worker that assembles it. The product should be seen on grass and should be colored appropriately to reduce chances of someone tripping over it. Since this device moves at a slow speed (approximately 20 feet per hour) so if it were to run into something, the damage would be minimal.

12.2 Ethical Considerations

An environmentally responsible business plan is becoming an increasingly vital component of any effective long-term strategy. This is not merely due to the growing number of Environmental laws businesses must comply with, but also due to the fact that the public expects that the business world will do its part in preserving the environment. Fortunately, plastic injection molding is a technology that can combine productivity, cost-effectiveness and an environmentally responsible production process in one package as most of the residual material can be recycled in the process itself. The majority of the parts of this sprinkler are made from injection molding, therefore, minimizing material waste. None of the parts require machining and thus, this even further reduce waste accumulation.

12.3 Human Factors

The only parts that are to be adjusted by humans are the dial (PLA-013) which adjusts the main water pipe (ALU-001) oscillating range, and the knob (PLA-054) which attaches to a garden hose. The knob is self-explanatory and a standard design that almost any consumer will be familiar with. The dial was redesigned from the original ace oscillating sprinkler design to be more legible. To fully explain the dial settings to users, documentation will be provided with the purchase of a mobile sprinkler.

13 Comparison to Oscillating Sprinkler

Once we had finished our novel mobile sprinkler design, we wished to do a final comparison to the original ace oscillating sprinkler studied in our reverse engineering report [1]. Table 10 below highlights important design metrics of each design.

Table 10: Summary Table of Ace Oscillating Sprinkler and Mobile Sprinkler

Metric	Original Oscillating Sprinkler	Novel Mobile Sprinkler
Total Unique Parts	26	42
Total Injection Molded Parts	21	30
Total Rubber Parts	2	2
Total Metal Parts	1	4
Total Standard Parts	2	6
Total Part Count	40	65
Total Number of Interactions	78	168
Theoretical Part Count Efficiency	10%	22%
Practical Part Count Efficiency	35%	72%
Total Cost to Manufacture	$7.15	$18.30
Estimated Sales Price	$8.51 (actual sales price $7.99)	$21.96
Break Even Point	30,000	29,000

Our novel mobile sprinkler contains 65 total parts compared to 40 on the original design, a little more than 1.5 times as much. However, the number of interactions on the mobile sprinkler, 168, is more than double the 78 interactions on the original sprinkler. This means that the mobile sprinkler contains more interactions per part (2.6) than the original sprinkler (1.6).

Even though there are more new parts on the mobile sprinkler, we were able to more than double the part count efficiencies. The theoretical part count efficiency went from 10% on the original design to 22% on the mobile design, and the practical part count efficiency went from 35% to 72%. This suggests that most of the new parts we designed were theoretically and practically critical to the function of the mobile sprinkler.

The breakeven points with a 20% profit margin for both the oscillating sprinkler and mobile sprinkler are roughly the same; 30,000 and 29,000 units respectively. Even though the breakeven point was decreased by an estimated 1,000 units, this metric can actually be interpreted as worsened. Since the oscillating sprinkler is a simpler and more inexpensive product, they will likely sell at a higher rate than mobile sprinklers, which are more expensive and therefore may not appeal to as many consumers. Therefore, it would take a mobile sprinkler manufacturer longer to recoup their expenses than it would take a manufacturer selling oscillating sprinklers, even if 1000 less mobile sprinkler units need to be sold

The final estimated sales price of the oscillating sprinkler was $8.51 (the actual sales price was $7.99) and the final estimated cost of the mobile sprinkler was $21.96. From the perspective of a consumer, we believe this is a great price point for the mobile sprinkler. If we imagine someone who has a large yard that cannot be fully covered by one or two oscillating sprinklers, the mobile sprinkler is a great option for them since one unit can cover the whole yard. Critically, the mobile sprinkler is less expensive than 3 oscillating sprinklers. And although the mobile sprinkler may require slightly more time from the consumer to set up the hose pattern, it is also more versatile than an oscillating sprinkler since its watering path is highly customizable. We believe that at a price point of roughly $22 dollars, the mobile sprinkler can be highly competitive in the market against other mobile sprinkler products, and more inexpensive alternatives such as oscillating sprinklers.

14 Summary and Conclusions

Following the initial reverse engineering project our team discovered several design improvements that could be introduced to the oscillating sprinkler system. One major aspect of the system that we saw as a flaw is the fact that the user would have to periodically move the sprinkler to different locations throughout the yard. So we decided to build upon the oscillating sprinkler design for our novel design project and make a design that autonomously moved throughout the yard while it waters.

The project started with a schedule and plan to develop design drawing, specification, requirement, etc. Black and Glass box models assisted in the initial development of the subsystems necessary and the initial patent search gave us some great insight into current designs and what solutions they developed for certain design problems. Since this was a novel project we were designing a market analysis was conducted to show that we do have a valid target market for the mobile sprinkler as well so we continued with the design process.

The minimum weight required for the assembly as well as parameters to provide a sufficient velocity for watering the yard were then calculated. These specifications were developed to provide design constraints for new parts and to ensure the final product would achieve what we wanted. From there, new components and parts were designed and modeled to build the mobile sprinkler assembly and develop drawings.

One of the most important parts of the project was to make sure our final design was not only possible to manufacture but that it would be more inexpensive than other similar products on the market today. A lot of time and thought went into each part and how it would be assembled and manufactured, and by using DFM and DFA principles, such as snap-in installation features, we were able to hit our cost targets. There would be future testing we would want to do to fine tune some aspects of the design but all in all the overall design project was a success.

15 Acknowledgements

We would like to thank Professor Riffell for his bi-weekly lectures and various online resources he provided to us throughout this project. We would also like to thank the ITLL staff for allowing us to use their tools to disassemble the sprinkler.

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17 Appendix

17.1 Cost Estimate Spreadsheet

See following pages.

#	Part Number	Material Cost and OME Calc					OME Calc Results		
		Weight of Part (lbs)	Material	Material cost per pound	Nominal Material	Scrap Fraction	Material Cost (Cm)	Total Est. Mfg Cost	Est. Sale Price
1	**A36-001**	0.0888	A36 Steel	$0.40	$0.036	0.20	$0.044	$0.133	$0.4
2	**ALU-001**	0.1168	Aluminium 6061	$0.70	$0.082	0.05	$0.086	$0.258	$0.8
3	**ALU-002**	0.0252	ASTM A513 Type 5	$0.70	$0.018	0.05	$0.019	$0.056	$0.2
4	**GCI-001**	2.4150	Gray Cast Iron	$0.64	$1.546	0.05	$1.627	$4.881	$14.6
5	**PLA-001**	0.0028	Nylon	$1.65	$0.005	0.05	$0.005	$0.015	$0.0
6	**PLA-002**	0.0032	ABS	$1.29	$0.004	0.05	$0.004	$0.013	$0.0
7	**PLA-003**	0.0040	ABS	$1.29	$0.005	0.05	$0.005	$0.016	$0.0
8	**PLA-004**	0.0206	ABS	$1.29	$0.027	0.05	$0.028	$0.084	$0.3
9	**PLA-005**	0.0011	Nylon	$1.65	$0.002	0.05	$0.002	$0.006	$0.0
10	**PLA-006**	0.0003	Nylon	$1.65	$0.001	0.05	$0.001	$0.002	$0.0
11	**PLA-007**	0.0095	Nylon	$1.65	$0.016	0.05	$0.017	$0.050	$0.1
12	**PLA-008**	0.0065	ABS	$1.29	$0.008	0.05	$0.009	$0.026	$0.1
13	**PLA-009**	0.0002	ABS	$1.29	$0.000	0.05	$0.000	$0.001	$0.0
14	**PLA-010**	0.0019	Nylon	$1.65	$0.003	0.05	$0.003	$0.010	$0.0
15	**PLA-011**	0.0068	Nylon	$1.65	$0.011	0.05	$0.012	$0.035	$0.1
16	**PLA-012**	0.0013	Nylon	$1.65	$0.002	0.05	$0.002	$0.007	$0.0
17	**PLA-013**	0.0100	ABS	$1.29	$0.013	0.05	$0.014	$0.041	$0.1
18	**PLA-015**	0.0041	Nylon	$1.65	$0.007	0.05	$0.007	$0.021	$0.1
19	**PLA-016**	0.0059	ABS	$1.29	$0.008	0.05	$0.008	$0.024	$0.1
20	**PLA-020**	0.0311	Nylon	$1.65	$0.051	0.05	$0.054	$0.162	$0.5
21	**PLA-025**	0.0031	Nylon	$1.65	$0.005	0.05	$0.005	$0.016	$0.0
22	**PLA-028**	0.2462	ABS	$1.29	$0.318	0.05	$0.334	$1.003	$3.0
23	**PLA-030**	0.0090	Nylon	$1.65	$0.015	0.05	$0.016	$0.047	$0.1
24	**PLA-031**	0.0031	ABS	$1.29	$0.004	0.05	$0.004	$0.013	$0.0
25	**PLA-035**	0.0012	ABS	$1.29	$0.002	0.05	$0.002	$0.005	$0.0
26	**PLA-036**	0.0004	Nylon	$1.65	$0.001	0.05	$0.001	$0.002	$0.0
27	**PLA-037**	0.0596	ABS	$1.29	$0.077	0.05	$0.081	$0.243	$0.7
28	**PLA-038**	0.0152	ABS	$1.29	$0.020	0.05	$0.021	$0.062	$0.2
29	**PLA-051**	0.0051	ABS	$1.29	$0.007	0.05	$0.007	$0.021	$0.1
30	**PLA-052**	0.0047	Nylon	$1.65	$0.008	0.05	$0.008	$0.024	$0.1
31	**PLA-053**	0.0049	ABS	$1.29	$0.006	0.05	$0.007	$0.020	$0.1
32	**PLA-054**	0.0309	ABS	$1.29	$0.040	0.05	$0.042	$0.126	$0.4
33	**PLA-055**	0.0605	ABS	$1.29	$0.078	0.05	$0.082	$0.246	$0.7
34	**PLA-056**	0.0558	ABS	$1.29	$0.072	0.05	$0.076	$0.227	$0.7
35	**RUB-001**	0.0023	Nitrile	$1.35	$0.003	0.05	$0.003	$0.010	$0.0
36	**RUB-002**	0.0025	Nitrile	$1.35	$0.003	0.05	$0.004	$0.011	$0.0
37	90480A005								
38	91771A120								
39	91772a238								
40	9452K190								
41	9452K250								
42	97828A634								

#	Part Number	Labor Cost Calc			Tooling Cost			
		Wages Cost per	Units produced per hour	Labor Cost (Cl)	Cost of Making Tooling	# parts in production run	tooling wear factor	Tooling Cost (Ct)
1	A36-001	$20	500	$0.04	$1,000	10000	1.0	$0.10
2	ALU-001	$20	100	$0.20	$2,000	10000	1.0	$0.20
3	ALU-002	$20	250	$0.08	$1,000	10000	1.0	$0.10
4	GCI-001	$20	100	$0.20	$2,000	10000	1.0	$0.20
5	PLA-001	$20	500	$0.04	$7,000	10000	0.1	$0.07
6	PLA-002	$20	500	$0.04	$12,000	10000	0.1	$0.12
7	PLA-003	$20	500	$0.04	$14,890	10000	0.1	$0.15
8	PLA-004	$20	500	$0.04	$15,413	10000	0.1	$0.15
9	PLA-005	$20	500	$0.04	$7,000	10000	0.1	$0.07
10	PLA-006	$20	500	$0.04	$14,415	10000	0.1	$0.14
11	PLA-007	$20	500	$0.04	$20,000	10000	0.1	$0.20
12	PLA-008	$20	500	$0.04	$15,000	10000	0.1	$0.15
13	PLA-009	$20	7500	$0.00	$10,000	150000	0.1	$0.01
14	PLA-010	$20	500	$0.04	$7,500	10000	0.1	$0.08
15	PLA-011	$20	500	$0.04	$16,620	10000	0.1	$0.17
16	PLA-012	$20	500	$0.04	$17,224	10000	0.1	$0.17
17	PLA-013	$20	500	$0.04	$7,500	10000	0.1	$0.08
18	PLA-015	$20	500	$0.04	$7,000	10000	0.1	$0.07
19	PLA-016	$20	500	$0.04	$7,000	10000	0.1	$0.07
20	PLA-020	$20	500	$0.04	$15,000	10000	0.1	$0.15
21	PLA-025	$20	500	$0.04	$7,000	10000	0.1	$0.07
22	PLA-028	$20	500	$0.04	$12,000	10000	0.1	$0.12
23	PLA-030	$20	500	$0.04	$15,000	10000	0.1	$0.15
24	PLA-031	$20	500	$0.04	$35,000	10000	0.1	$0.35
25	PLA-035	$20	500	$0.04	$7,000	10000	0.1	$0.07
26	PLA-036	$20	500	$0.04	$30,000	10000	0.1	$0.30
27	PLA-037	$20	500	$0.04	$15,000	10000	0.1	$0.15
28	PLA-038	$20	500	$0.04	$100,000	10000	0.1	$1.00
29	PLA-051	$20	500	$0.04	$16,830	10000	0.1	$0.17
30	PLA-052	$20	500	$0.04	$16,830	10000	0.1	$0.17
31	PLA-053	$20	500	$0.04	$16,667	10000	0.1	$0.17
32	PLA-054	$20	500	$0.04	$16,620	10000	0.1	$0.17
33	PLA-055	$20	500	$0.04	$16,467	10000	0.1	$0.16
34	PLA-056	$20	500	$0.04	$16,467	10000	0.1	$0.16
35	RUB-001	$20	250	$0.08	$7,000	10000	0.1	$0.07
36	RUB-002	$20	250	$0.08	$7,000	10000	0.1	$0.07
37	90480A005							
38	91771A120							
39	91772a238							
40	9452K190							
41	9452K250							
42	97828A634							

#	Part Number	Equipment Cost					Equip Cost (Ce)	Overhead cost
		capital equipment cost	load factor	capital write-off time (years)	capital write-off time (hours)	equip sharing fraction		overhead hourly rate ($/hr)
1	A36-001	$500,000	0.50	5	43830	1.000	$0.05	$60.00
2	ALU-001	$20,000	0.10	5	43830	1.000	$0.05	$60.00
3	ALU-002	$20,000	0.10	5	43830	1.000	$0.02	$60.00
4	GCI-001	$20,000	0.05	5	43830	1.000	$0.09	$60.00
5	PLA-001	$500,000	0.50	5	43830	0.077	$0.004	$60.00
6	PLA-002	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
7	PLA-003	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
8	PLA-004	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
9	PLA-005	$500,000	0.50	5	43830	0.077	$0.004	$60.00
10	PLA-006	$500,000	0.50	5	43830	0.077	$0.004	$60.00
11	PLA-007	$500,000	0.50	5	43830	0.077	$0.004	$60.00
12	PLA-008	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
13	PLA-009	$1,000,000	0.50	5	43830	0.053	$0.000	$60.00
14	PLA-010	$500,000	0.50	5	43830	0.077	$0.004	$60.00
15	PLA-011	$500,000	0.50	5	43830	0.077	$0.004	$60.00
16	PLA-012	$500,000	0.50	5	43830	0.077	$0.004	$60.00
17	PLA-013	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
18	PLA-015	$500,000	0.50	5	43830	0.077	$0.004	$60.00
19	PLA-016	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
20	PLA-020	$500,000	0.50	5	43830	0.077	$0.004	$60.00
21	PLA-025	$500,000	0.50	5	43830	0.077	$0.004	$60.00
22	PLA-028	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
23	PLA-030	$500,000	0.50	5	43830	0.077	$0.004	$60.00
24	PLA-031	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
25	PLA-035	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
26	PLA-036	$500,000	0.50	5	43830	0.077	$0.004	$60.00
27	PLA-037	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
28	PLA-038	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
29	PLA-051	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
30	PLA-052	$500,000	0.50	5	43830	0.077	$0.004	$60.00
31	PLA-053	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
32	PLA-054	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
33	PLA-055	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
34	PLA-056	$1,000,000	0.50	5	43830	0.053	$0.005	$60.00
35	RUB-001	$1,000,000	0.50	5	43830	0.053	$0.01	$60.00
36	RUB-002	$1,000,000	0.50	5	43830	0.053	$0.01	$60.00
37	90480A005							
38	91771A120							
39	91772a238							
40	9452K190							
41	9452K250							
42	97828A634							

#	Part Number	Overhead Cost (Coh)	FINAL UNIT COST EST. ($ per unit)	Break Even Point Calc G&A Expenses	Depreciation	Additional Factory Expenses	Sales Expenses	Profit (20%)	Variable Costs (v)
1	**A36-001**	$0.12	$0.3500	$1,200	$5,000	$300	$500	$0.07	$0.08
2	**ALU-001**	$0.60	$1.1317	$1,200	$5,000	$300	$500	$0.23	$0.29
3	**ALU-002**	$0.24	$0.4568	$1,200	$5,000	$300	$500	$0.09	$0.10
4	**GCI-001**	$0.60	$2.7182	$1,200	$5,000	$300	$500	$0.54	$1.83
5	**PLA-001**	$0.12	$0.2384	$1,200	$5,000	$300	$500	$0.05	$0.04
6	**PLA-002**	$0.12	$0.2891	$1,200	$5,000	$300	$500	$0.06	$0.04
7	**PLA-003**	$0.12	$0.3192	$1,200	$5,000	$300	$500	$0.06	$0.05
8	**PLA-004**	$0.12	$0.3469	$1,200	$5,000	$300	$500	$0.07	$0.07
9	**PLA-005**	$0.12	$0.2354	$1,200	$5,000	$300	$500	$0.05	$0.04
10	**PLA-006**	$0.12	$0.3082	$1,200	$5,000	$300	$500	$0.06	$0.04
11	**PLA-007**	$0.12	$0.3800	$1,200	$5,000	$300	$500	$0.08	$0.06
12	**PLA-008**	$0.12	$0.3236	$1,200	$5,000	$300	$500	$0.06	$0.05
13	**PLA-009**	$0.01	$0.0180	$1,200	$5,000	$300	$500	$0.00	$0.00
14	**PLA-010**	$0.12	$0.2418	$1,200	$5,000	$300	$500	$0.05	$0.04
15	**PLA-011**	$0.12	$0.3415	$1,200	$5,000	$300	$500	$0.07	$0.05
16	**PLA-012**	$0.12	$0.3380	$1,200	$5,000	$300	$500	$0.07	$0.04
17	**PLA-013**	$0.12	$0.2534	$1,200	$5,000	$300	$500	$0.05	$0.05
18	**PLA-015**	$0.12	$0.2406	$1,200	$5,000	$300	$500	$0.05	$0.05
19	**PLA-016**	$0.12	$0.2428	$1,200	$5,000	$300	$500	$0.05	$0.05
20	**PLA-020**	$0.12	$0.3675	$1,200	$5,000	$300	$500	$0.07	$0.09
21	**PLA-025**	$0.12	$0.2389	$1,200	$5,000	$300	$500	$0.05	$0.05
22	**PLA-028**	$0.12	$0.6191	$1,200	$5,000	$300	$500	$0.12	$0.37
23	**PLA-030**	$0.12	$0.3291	$1,200	$5,000	$300	$500	$0.07	$0.06
24	**PLA-031**	$0.12	$0.5190	$1,200	$5,000	$300	$500	$0.10	$0.04
25	**PLA-035**	$0.12	$0.2364	$1,200	$5,000	$300	$500	$0.05	$0.04
26	**PLA-036**	$0.12	$0.4642	$1,200	$5,000	$300	$500	$0.09	$0.04
27	**PLA-037**	$0.12	$0.3957	$1,200	$5,000	$300	$500	$0.08	$0.12
28	**PLA-038**	$0.12	$1.1854	$1,200	$5,000	$300	$500	$0.24	$0.06
29	**PLA-051**	$0.12	$0.3401	$1,200	$5,000	$300	$500	$0.07	$0.05
30	**PLA-052**	$0.12	$0.3399	$1,200	$5,000	$300	$500	$0.07	$0.05
31	**PLA-053**	$0.12	$0.3381	$1,200	$5,000	$300	$500	$0.07	$0.05
32	**PLA-054**	$0.12	$0.3730	$1,200	$5,000	$300	$500	$0.07	$0.08
33	**PLA-055**	$0.12	$0.4116	$1,200	$5,000	$300	$500	$0.08	$0.12
34	**PLA-056**	$0.12	$0.4052	$1,200	$5,000	$300	$500	$0.08	$0.12
35	**RUB-001**	$0.24	$0.4029	$1,200	$5,000	$300	$500	$0.08	$0.08
36	**RUB-002**	$0.24	$0.4032	$1,200	$5,000	$300	$500	$0.08	$0.08
37	90480A005		$0.0100						
38	91771A120		$0.1100						
39	91772a238		$0.0900						
40	9452K190		$0.0400						
41	9452K250		$0.0400						
42	97828A634		$0.0100						

						Numbers for BOM			
#	Part Number	Fixed Costs (f)	Sales Price (P)	Break Even Point (divided by qty)	Sales Price for 5000	Qty	Indiv. Cost	Total Cost	Total Sales Price (assume 20% profit)
1	A36-001	$7,000	$0.42	20856	$1.48	1	$0.35	$0.35	$0.42
2	ALU-001	$7,000	$1.36	6530	$1.69	1	$1.13	$1.13	$1.36
3	ALU-002	$7,000	$0.55	15569	$1.50	1	$0.46	$0.46	$0.55
4	GCI-001	$7,000	$3.26	4878	$3.23	1	$2.72	$2.72	$3.26
5	PLA-001	$7,000	$0.29	29023	$1.44	1	$0.24	$0.24	$0.29
6	PLA-002	$7,000	$0.35	23130	$1.44	1	$0.29	$0.29	$0.35
7	PLA-003	$7,000	$0.38	20738	$1.45	1	$0.32	$0.32	$0.38
8	PLA-004	$7,000	$0.42	20097	$1.47	1	$0.35	$0.35	$0.42
9	PLA-005	$7,000	$0.28	29095	$1.44	1	$0.24	$0.24	$0.28
10	PLA-006	$7,000	$0.37	21257	$1.44	1	$0.31	$0.31	$0.37
11	PLA-007	$7,000	$0.46	17521	$1.46	1	$0.38	$0.38	$0.46
12	PLA-008	$7,000	$0.39	20617	$1.45	1	$0.32	$0.32	$0.39
13	PLA-009	$7,000	$0.02	25110	$1.40	15	$0.02	$0.27	$0.32
14	PLA-010	$7,000	$0.29	28355	$1.44	1	$0.24	$0.24	$0.29
15	PLA-011	$7,000	$0.41	19553	$1.45	1	$0.34	$0.34	$0.41
16	PLA-012	$7,000	$0.41	19266	$1.44	1	$0.34	$0.34	$0.41
17	PLA-013	$7,000	$0.30	27946	$1.45	1	$0.25	$0.25	$0.30
18	PLA-015	$7,000	$0.29	14485	$1.45	2	$0.24	$0.48	$0.58
19	PLA-016	$7,000	$0.29	28763	$1.45	1	$0.24	$0.24	$0.29
20	PLA-020	$7,000	$0.44	10086	$1.49	2	$0.37	$0.74	$0.88
21	PLA-025	$7,000	$0.29	29011	$1.45	1	$0.24	$0.24	$0.29
22	PLA-028	$7,000	$0.74	9495	$1.77	2	$0.62	$1.24	$1.49
23	PLA-030	$7,000	$0.39	10314	$1.46	2	$0.33	$0.66	$0.79
24	PLA-031	$7,000	$0.62	12098	$1.44	1	$0.52	$0.52	$0.62
25	PLA-035	$7,000	$0.28	28915	$1.44	1	$0.24	$0.24	$0.28
26	PLA-036	$7,000	$0.56	13557	$1.44	1	$0.46	$0.46	$0.56
27	PLA-037	$7,000	$0.47	19777	$1.52	1	$0.40	$0.40	$0.47
28	PLA-038	$7,000	$1.42	5140	$1.46	1	$1.19	$1.19	$1.42
29	PLA-051	$7,000	$0.41	19384	$1.45	1	$0.34	$0.34	$0.41
30	PLA-052	$7,000	$0.41	19456	$1.45	1	$0.34	$0.34	$0.41
31	PLA-053	$7,000	$0.41	19493	$1.45	1	$0.34	$0.34	$0.41
32	PLA-054	$7,000	$0.45	19147	$1.48	1	$0.37	$0.37	$0.45
33	PLA-055	$7,000	$0.49	18827	$1.52	1	$0.41	$0.41	$0.49
34	PLA-056	$7,000	$0.49	18892	$1.52	1	$0.41	$0.41	$0.49
35	RUB-001	$7,000	$0.48	17491	$1.48	1	$0.40	$0.40	$0.48
36	RUB-002	$7,000	$0.48	17489	$1.48	1	$0.40	$0.40	$0.48
37	90480A005					2	$0.01	$0.02	$0.02
38	91771A120			**Total Cost to Make**		1	$0.11	$0.11	$0.13
39	91772a238			**$18.30**		1	$0.09	$0.09	$0.11
40	9452K190					1	$0.04	$0.04	$0.05
41	9452K250			**Total Selling Price**		1	$0.04	$0.04	$0.05
42	97828A634			**$21.96**		5	$0.01	$0.05	$0.06

17.2 Engineering Drawings

See following pages.