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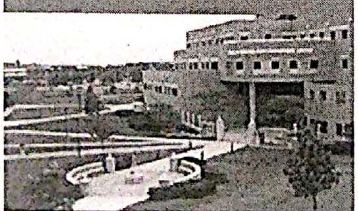

College of Engineering and Computer Science

Final Report for
ME 4910/4920, Capstone Design I & II
Fall 2018 & Spring 2019

MALAWI WASHING MACHINE

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EXECUTIVE SUMMARY

Hospitals in the African nation of Malawi require a washing machine that can be manufactured locally. Electricity is scarce, meaning a human powered washing machine is being considered for use in hospitals. The machine must be easily constructed, use materials readily available, and be easy to use. This machine will provide a sanitary method of cleaning fabrics at hospitals. The machine will be designed, built, and tested at Wright State University. Instructions of the final design will then be sent to Malawi to be constructed and operated on site.

The design consists of a frame, container, power delivery mechanism, and agitator. The frame is constructed out of metal tubing, which serves to both hold the container in place and ensure power delivery is properly performed. The container is a 55-gallon drum which holds both the sheets and agitator, and it is drainable once a cycle is finished.

Power delivery is performed using a hand crank. The development of the power delivery went through many iterations, with initial constructions utilizing a ratchet mold strategy. The mold was untenable due to time constraints and construction difficulty. A ratchet was devised using threaded rods through the central agitator's shaft. The rods would serve as teeth and be impacted by a stepper. After actual testing, the power was not transmitted effectively enough to be viable, and power delivery moved to a hand crank instead. Tests of the hand crank found it to be easy on the operators, and power was both transmitted and maintained properly. Further iterations of the hand crank were made as necessary.

The agitation is performed using different PVC tubes, connectors, and joints. The PVC forms a central shaft with fins extending outward to agitate the water. Both the number and construction of the fins were tested on multiple parameters, with the results of each test used to compare the designs. The final agitator utilizes four fins, each consisting of two pipes joined with an elbow.

1 INTRODUCTION

Hospitals in Malawi need a washing machine to clean sheets for patients. Due to a lack of electricity and running water, the machine needs to be human powered. Additionally, a couple restrictions are necessary for the design. First, it must be manufacturable in Malawi, meaning the machine construction cannot necessitate the use of power tools or be excessively complex. Second, any and all materials used must be procured within Malawi. If a part of the design cannot be made or located in Malawi, said part will need to be sent over. Lastly, the design must be easy to use for an extended period of time to ensure the clothes are properly cleaned.

Two previous iterations of this project have been done with separate designs. The first design featured a slightly angled, upright drum attached to a bicycle. The bicycle was pedaled to spin an agitation device at the bottom of the drum. A combination of gravity and spinning would serve to agitate the water and clean the clothes. The second design laid the drum on its side, held in place by a complex metal frame. This metal frame would attach to a bicycle as well, and pedaling the bicycle provided power indirectly to the agitator. The torque was transferred to both ends of the drum through bicycle chains and gears, spinning a central shaft attached to an agitation device. Both devices utilized bicycles, which, while common, are more valuable to the people of Malawi.

The new design seeks to maintain effectiveness while remedying many of the issues from previous designs, such as: the use of bicycles as a powering mechanism, making the entire machine easily repairable and modular, and ensuring the operator can maintain power input. Additional concerns such as draining of the drum and heating of the water were considered, though deemed outside of the scope of this project. The machine design was approached through research of old, patented washing machines. Once a design was decided upon, calculations for stress within important parts of the machine were performed. Additionally, different experimental tests were performed to ensure parts could withstand the forces that would be applied. Aspects of the machine like the stepper were designed experimentally, since comfortability and ease of use are difficult to empirically measure.

2 BACKGROUND

Research of this project consists predominantly of old, patented designs which provided ideas for the problem of Malawian hospitals. The initial designs were inspired by patent 636556, which used a rotating apparatus to agitate the clothes [1]. The clothes are held in a container while the operator turns the apparatus. Other ideas were drawn from patents 408690 [2], 27391 [3], and 20230 [4]. Patent 408690 holds the clothes within a cylindrical container to be agitated by the operator through turning a lever. The container is held off the ground through the use of two stands at either end and uses multiple gears to transmit the operator input. Patents 27391 and 20230 both operate similarly to a "bingo cage", where a operator turns a hand crank to spin an internal mechanism within the container. Other patents, such as 20230 and 661514, featured designs which focused on crushing or grinding the clothes against the surface of the container and some press moved by the operator [5]. This pressing would provide a large amount of agitation, albeit through use of a complex mechanism and geometry.

Two groups prior to this group have developed designs for this project. The first group utilized an upright 55-gallon drum, with an agitator at the bottom, shown in Figure 1 [6]. The drum was slightly angled, allowing the clothes to agitate more thoroughly. The agitation used a series of rods radiating from a central shaft, which would be turned from operator input from a bike. The bike was modified to fix in place, and the back tire was removed to allow the chain to connect to the central shaft.

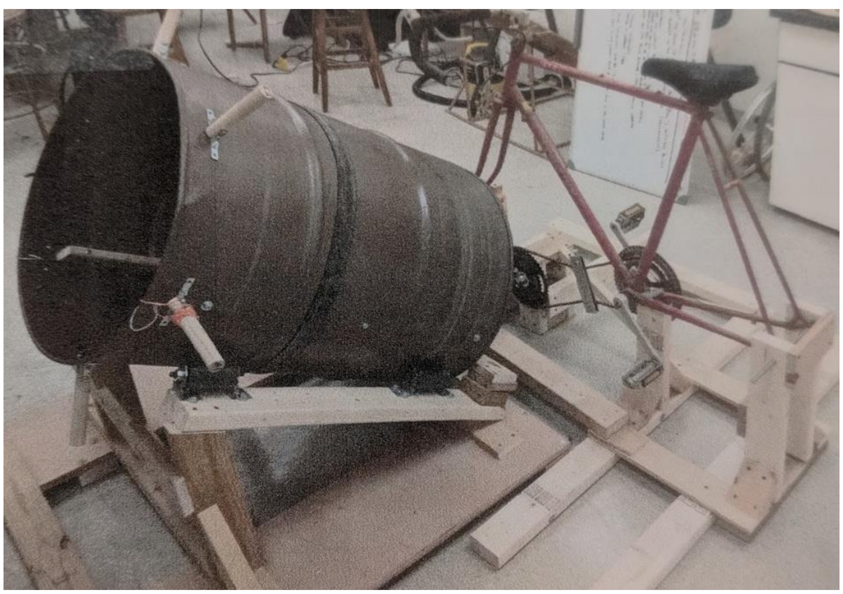

Figure 1: Washing Machine from 2016-2017 Source: (Grey et al., 2017)

The second group laid a drum on its side and attached it to a metal frame, shown in Figure 2 [7]. This metal frame held a central shaft that ran through the middle of the drum. This shaft was turned through the use of three different bicycle gears and chains. The bicycle was fixed to the front of the frame, allowing the operator to turn one gear. The motion spun gears at the ends of a shaft, which in turn spun gears at either ends of the drum, rotating the central shaft. Affixed to the central shaft was an agitator which rotated around the length of the drum.

Figure 2: Washing Machine from 2017-2018 Source: (Moussa, Purvis and Spencer, 2018)

The design to be implemented in Malawi utilized many ideas from these patents and previous designs including the container shape, container supports, agitation, and power delivery.

3 CONCEPT GENERATION AND CONCEPT SELECTION

The Malawi washing machine has a wide variety of parts needed to operate effectively and efficiently. All the parts must be readily available in Malawi, limiting the materials that can be used and increasing the need for creative solutions. Most of the washing machine was constructed out of metal tubing and PVC pipe due to their availability in Malawi. The machine used a 55-gallon drum, resting on top of a frame of metal tubing. An agitator made of PVC was placed inside the drum and attached to a PVC hand crank to rotate it. The agitator was held to the frame by PVC bearings that allowed the agitator to spin while maintaining its position.

Frame and Container

The main body of the washing machine consists of a frame made of metal tubing, PVC bearings that connect the agitator to the frame, and the drum used to contain the load of sheets and water.

Frame:

The frame for the washing machine needed to be strong enough to support a drum containing water and clothes and be easily communicated. The frame for the drum was originally made of wood so that it could be modified as needed. This wooden frame can be seen below in Figure 3. The frame consisted of an “inner box” that the drum rested on top of, and an “outer box” that holds the drum in place. The final frame consists of half-inch steel tubing, similar to the design seen in Figure 4. Welding is a common skill in Malawi, so there should be no problem in building the frame out of the metal tubing.

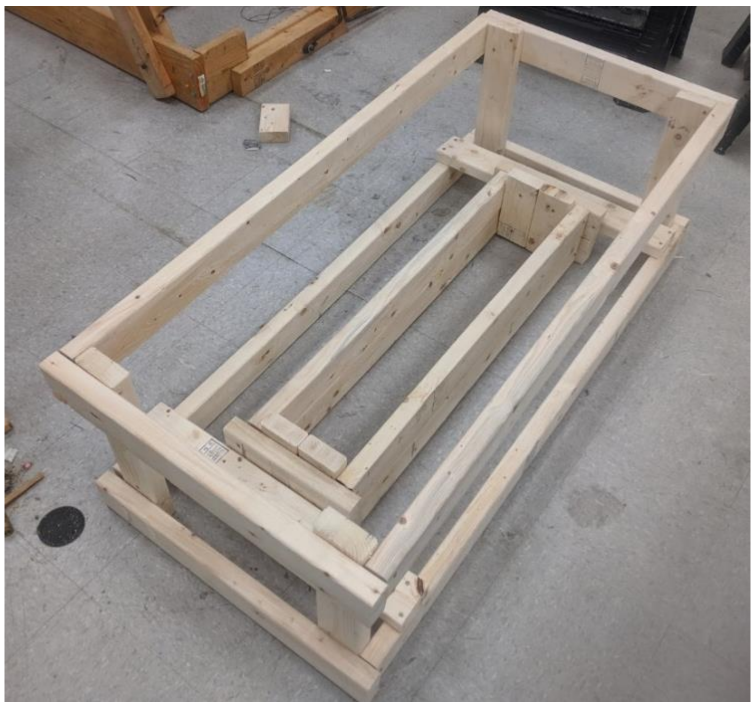

Figure 3: Wooden Frame

Figure 4: Metal Frame

Bearings:

One problem that arose during construction was contact between the drum and the PVC agitator. This contact could lead to cuts and deformations in the agitator as it spins. To remedy this, bearings were created from a larger sized PVC. It was found that if PVC is boiled in water, it can then be bent into any shape necessary. By boiling the PVC and squeezing it around the smaller sized pipe, a suitable bearing for the agitator can be constructed. These bearings are shown below in Figure 5.

Figure 5: PVC Bearings

Drum:

It was decided that a 55-gallon drum would serve as the body of the washing machine. Drums are large enough to hold the necessary amount of water, and both plastic and metal drums are available in Malawi, though either type may be used. Figures 6 and 7 show the use of a plastic and metal drum respectively.

Figure 6: Wooden Frame with Plastic Drum

Figure 7: Metal Frame with Metal Drum

Power Delivery

For proper agitation to occur, an adequate amount of power must be applied to the central shaft of the agitator. To do this, two different methods have been considered: a ratchet with a stepper and a crank.

Ratchet:

For the original transmission design, a ratchet was chosen to conserve energy, a design which went through several iterations. The original plan was to create a mold that would allow for the ratchet to be made from concrete. To do this a sample ratchet was 3-D printed (Figure 8) and placed into different molds to determine which material is ideal. The first test was performed by letting Bondo harden around the printed ratchet, seen in Figure 9. As the Bondo hardened, however, the ratchet became stuck in the mold, making this option infeasible.

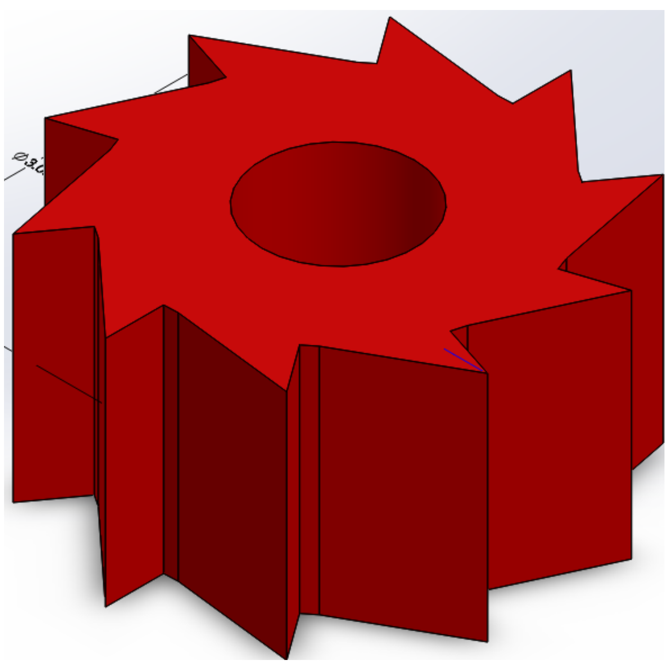

Figure 8: CAD Ratchet

Figure 9: Attempted Bondo Mold

Since the Bondo proved to be an ineffective mold, a different type of mold was needed. Silicone caulk was known to be available in Malawi, making it a natural choice for a mold. Several types of silicone recipes were tested to see which one would form the best mold. A mold consisting of cornstarch and silicone (shown in Figure 10) did not show great enough detail, and a hand soap and silicone mold (shown in Figure 11) took more than a month to properly set. A series of various ratios of silicone, cornstarch, and hand soap were then tested to find an adequate mold (Figure 12), however none proved effective.

Figure 10: Cornstarch and Silicone Mold

Figure 11: Soap and Silicone Mold

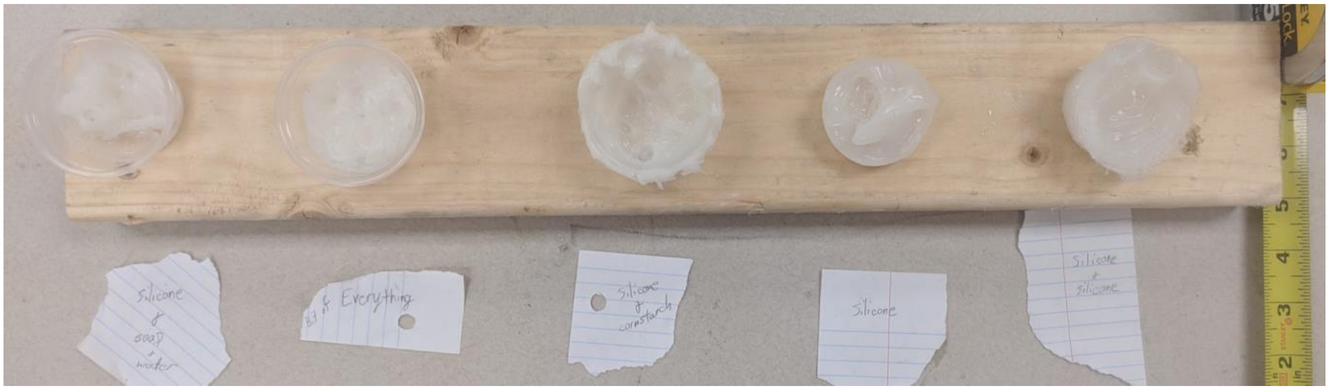

Figure 12: Different Mold Combinations (Left to Right) Silicone and Soap, a Bit of Everything, Silicone and Cornstarch, Silicone, Layered Silicone

Since the idea for a molded ratchet proved to be ineffective, a different ratchet construction method was necessary. To do this, a ratchet made from threaded rod was considered. As shown in Figure 13, holes were drilled through a PVC pipe at half inch increments. Threaded rods were placed through the drilled holes, and nuts were placed on each end to hold the rod in place. Tests on the first iteration of the ratchet (Figure 14) showed that the threaded rods were slightly out of line, and the nuts would become loose after repeated use. To remedy this, a drill press was used to drill precise holes in the PVC pipe, and two nuts were placed on each end of the threaded rods (Figure 15)

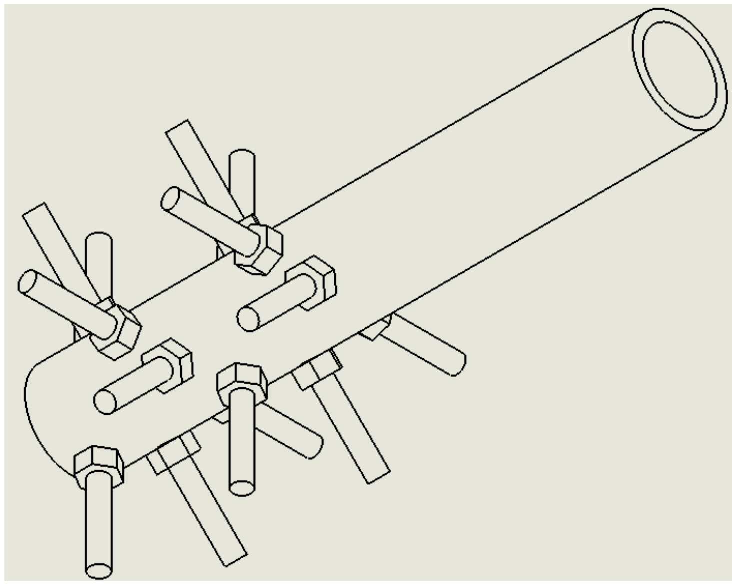

Figure 13: Threaded Rod Ratchet CAD Model

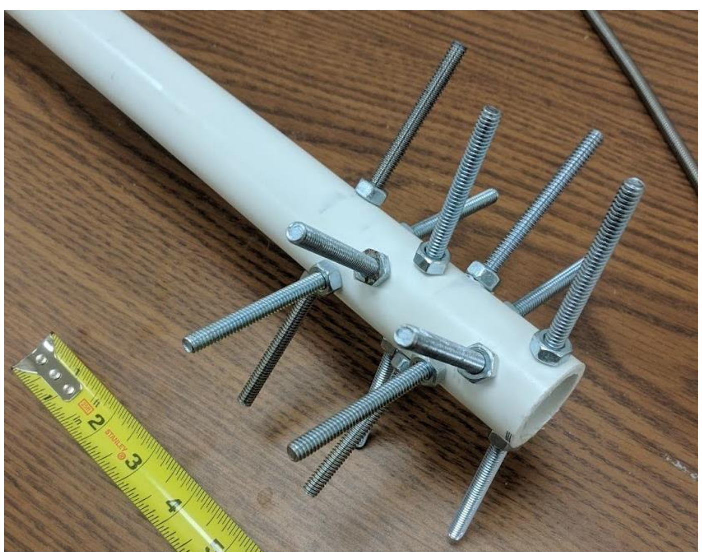

Figure 14: First Iteration Treaded Rod Ratchet

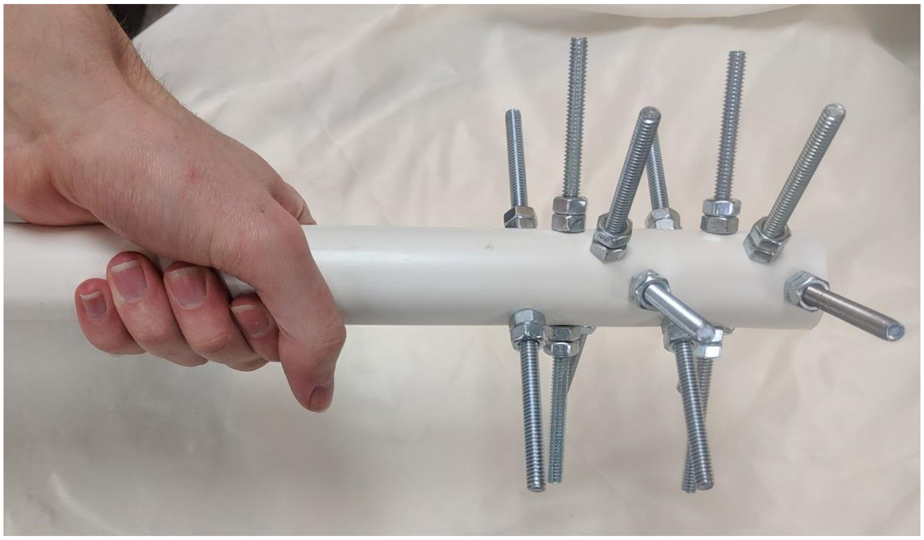

Figure 15: Precision Threaded Rod Ratchet

Stepper:

To effectively deliver force to the ratchet, a stepper was designed and constructed (Figure 16). A square PVC frame was built with crossing pipes extending upward with a PVC pipe attached to a “stepping board” resting on the intersection. The pivot for the board was set at seven inches, a height comfortable for all team members. A door hinge was attached to the ratchet end of the stepping board to serve as a pawl, allowing the ratchet to turn when the stepping board rises and minimize resistance when lowered. A small piece of bent metal was attached behind the door hinge to stop it from folding over. Unfortunately, at the ideal height, the force required to turn the ratchet was much greater than previously anticipated. The extra force caused a greater torque on the ratchets in the agitator, which could potentially lead to deformation in the PVC. Therefore, a different powering system was needed.

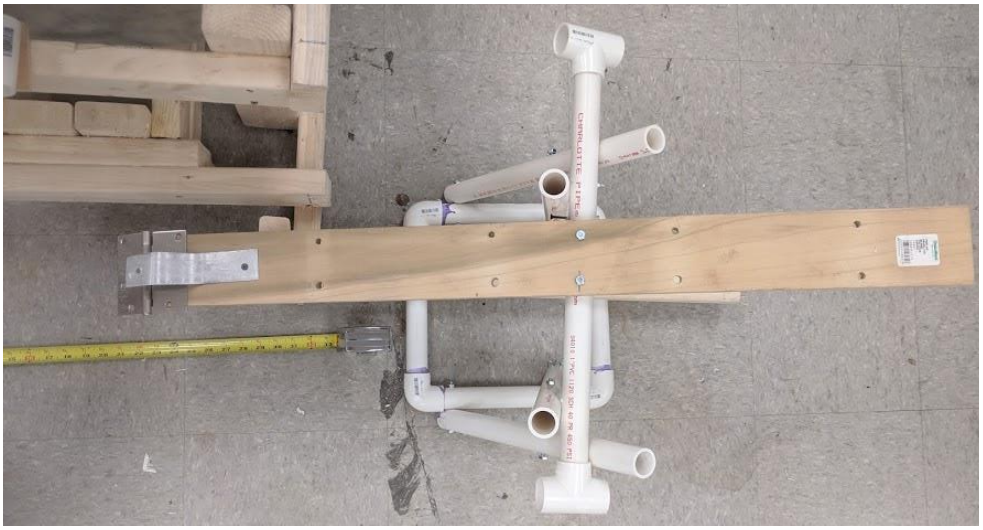

Figure 16: Stepper

Hand Crank:

A hand crank was chosen for the second power delivery system. A section of PVC pipe connected directly to the agitator turns to cause the rotation. By manually rotating the PVC with a lever arm, momentum and power were conserved, creating a more efficient power delivery system. To make the crank more effective, a second handle was added to the opposite end of the hand crank, as seen in Figure 17. This keeps the operator from needing to bend downward as the crank reaches the bottom of its path.

Figure 17: Test Hand Crank

Agitation

To properly stir both the water and the clothes, some form of agitation was required. It was decided that agitation would be caused by a PVC agitator rotating inside of the drum. The agitator consists of four parts: a central shaft, fins, a power delivery shaft, and a support tail. The central shaft was constructed by connecting PVC T-joints with small sections of PVC pipe. One end of the central shaft would be connected to a PVC pipe called the power delivery shaft, which receives the torque applied by the operator. The other end of the central shaft was a capped PVC pipe called the support tail, used to balance and support the agitator. The fins of the agitator were made from small, parallel PVC pipes connected by PVC elbows, T-joints, and shortened pipes. For the first iteration of the agitator, the fin was made from three parallel pipes connected at the top. The fins were oriented at 120-degree angles, and all parts were glued into place. Figures 18 and 19 show the construction and organization of joints for the first iteration of the agitator, which featured three fins supported by three sections of PVC.

Figure 18: Construction of First Iteration of Agitator

Figure 19: Final First Iteration of Agitator

The first iteration of the agitator worked well for testing purposes but had some flaws that needed to be fixed. Each connection in this agitator was glued, so that each joint would be fixed. However, this design was not modular and did not allow parts to be easily replaced. To remedy this, the central shaft and each individual fin was glued, and the fins and power delivery shaft were bolted onto the central shaft, allowing for all parts to be removed and replaced if damage occurs. It was determined that the inclusion of bolts on the fins was superfluous and caused sheets to catch on the shaft more often. This interference caused a higher chance of tearing the sheets, making gluing the fins the better option. The original agitator was also difficult to correctly assemble. Because of this, three agitators were designed and tested, each built with different types of fins. Each agitator is shown below in Figure 20. One agitator used singular PVC pipes capped at the ends as fins. This agitator (Mono-Fin) is shown as the left agitator in the figure below. The construction table of the Mono-Fin is shown on Table 1. The second agitator (Bi-Fin) used two consecutive parallel pipes connected with elbows as fins. These fins were oriented at ninety-degree angles. The construction table of the Bi-Fin is shown on Table 2. This agitator is shown in the middle of the figure below. The final agitator (Tri-Fin) was created in the same manner as the original agitator and is shown on the right of the image below. The construction table of the Tri-Fin is shown on Table 3.

Figure 20: (Left to Right) Mono-Fin, Bi-Fin, Tri-Fin

Mono-Fin			
Part	**Quantity**	**Weight**	**Cut Length**
Cap	9	1.0 oz.	
T-Joint	9	2.3 oz.	
Fin PVC Section	9	3.3 oz.	7.5”
Reinforcement PVC	8	0.6 oz.	1.5”
Total Weight (oz.)		64.2	
Total Weight (lbs.)		4.0125	

Table 1: Construction Table of Mono-Fin

Bi-Fin			
Part	**Quantity**	**Weight**	**Cut**
Elbow	8	1.7 oz.	
T-Joint	8	2.3 oz.	
Fin PVC Section	8	3.3 oz.	7.5”

Reinforcement PVC	11	0.6 oz.	1.5”
Total Weight (oz.)		65.0	
Total Weight (lbs.)		4.0625	

Table 2: Construction Table of Bi-Fin

Tri-Fin			
Part	**Quantity**	**Weight**	**Cut**
Elbow	6	1.7 oz.	
T-Joint	12	2.3 oz.	
Fin PVC Section	9	3.3 oz.	7.5”
Fin Reinforcement PVC	3	3.5 oz.	8.25”
Reinforcement PVC	8	0.6 oz.	1.5”
Total Weight (oz.)		82.8	
Total Weight (lbs.)		5.175	

Table 3: Construction Table of Tri-Fin

4 FINAL DESIGN

The final design was achieved through testing of the prototype model. The washing machine operates by having a hand crank power system to provide a rotational force to the bi-fin agitator contained inside the 55-gallon steel drum. The system is held in place with a frame welded from half-inch steel square tubing.

The overall design was chosen based on the following criteria: manufacturability, communicability, availability of parts, and ease of use. Each of these categories had an equal weighting as each plays a significant role in the ability of those reproducing this design in Malawi.

Manufacturability was crucial in determining the final design as Malawi does not have access to the same tools that are readily available here; therefore, the design had to limit the number of complex geometries and drilled holes.

Communicability played an important factor as well since difficult designs are much harder to convey to a society where illiteracy is prevalent. Since no members of the team will be traveling to Malawi to explain how to build the washing machine, a simpler design was desired. The design therefore had to be simple enough to display in an instruction manual.

Since Malawi is not a wealthy country, they are limited in terms of parts that are readily available to them. This limited the design to materials that could be easily obtained, meaning all designs were focused around these materials.

Ease of use was a pivotal aspect of the project as people will be operating this washing machine for extended periods of time. Should it be too difficult to apply a force over this period, the design would not be viable; all designs were tested to determine which would cause the least amount of operator strain while still satisfying all other criteria.

Due to the scarcity of materials, cost was also considered as a criterion; cost held less weight than the other criteria such as material availability due to the low estimated cost of construction.

The metal frame was chosen for durability and stability. It provided a design that would hold the weight of the washing machine at full capacity while preventing unwanted movement. The frame was simplistic and easy to communicate, though weld quality could be a concern. The material used was half-inch plain steel square tubing, though the material switch to more readily available materials if a need is determined by those reproducing the design. Additionally, dimensions of the frame can be altered to fit specific needs such as different drum sizes or a preference for a higher or lower central shaft height. The overall cost of the material is seen blow in Table 4.

Part Description	Purchased From	Quantity	Cost per Item	Overall Cost
Everbilt 1/2 in. x 72 in. Plain Steel Square Tube with 1/16 in. Thickness	Home Depot	10	$11.22	$112.20

Table 4: Overall Cost of the Frame

The hand crank was chosen as the power delivery system due to the relative ease involved in constructing it when compared to the multi-component stepper design. Additionally, the assembly of the hand crank is easily conveyed with pictures. The 1” PVC used roughly corresponds to the 25 mm PVC available in Malawi, and, since the fittings used are available too, it is feasible to construct the design in Malawi. The overall cost of the hand crank can be seen in Table 5.

Part Description	Purchased From	Quantity	Cost per Item	Overall Cost
1' PVC ELBOW 90D SXS	Home Depot	2	$1.14	$2.28

1" PVC TEE SXSXS	Home Depot	1	$1.34	$1.34
1” x 10’ PVC40 PE Pipe	Home Depot	1	$3.33	$3.33
			Total Cost	$6.95

Table 5: Overall Cost of Hand Crank

The bi-fin agitator was chosen over the other two agitator designs due to the ease of constructing it. Of the three, it is the only agitator that can be built outside of the drum and inserted; the other two agitators must be assembled in the space within the drum. The assembly is easy to demonstrate with an instruction manual, and all materials are found in Malawi. The total cost for the bi-fin is seen in Table 6.

Part Description	Purchased From	Quantity	Cost per Item	Overall Cost
1' PVC ELBOW 90D SXS	Home Depot	8	$1.14	$9.12
1" PVC TEE SXSXS	Home Depot	8	$1.34	$10.72
1” x 10’ PVC40 PE Pipe	Home Depot	1	$3.33	$3.33
			Total Cost	$23.17

Table 6: Overall Cost of Agitator

The steel drum was chosen over a plastic drum of similar dimensions because one is already present at the hospital in Malawi. The average cost of the steel drum is usually around $100.00.

Adding the cost of these individual components of the design, and including the drum, the overall cost of the design is $265.75. For the project, $200.00 was allotted per group member which gave an operational budget of $1000.00 for the duration of the project. This amount is satisfactory, and no additional fundraising was done. A full bill of materials with hardware included can be seen in Table 7.

Item Description	Supplier	Quantity	Cost per Item	Total Cost
13 mm Steel Tubing	Home Depot	10	$11.22	$112.20
Rubber Inner Tube	Bell Sports	1	$4.96	$4.96
55 Gallon Drum	Uline	1	$94.00	$94.00
6.35 mm Bolts 7.75cm	Home Depot	2	$0.24	$0.48
6.35 mm Bolts 5cm	Home Depot	10	$0.20	$2.00

6.35 mm Hex Nuts	Home Depot	24	$0.07	$1.68
55 mm PVC Pipe	Home Depot	1	$3.98	$3.98
25 mm PVC Pipe	Home Depot	2	$3.33	$6.66
25 mm PVC 90° Elbows	Home Depot	10	$1.14	$11.40
25 mm PVC T-Joint	Home Depot	8	$1.34	$10.72
25 mm PVC Cap	Home Depot	2	$0.83	$1.66
6.35 mm Blots or Screws	Home Depot	26	$0.20	$5.20
6.35 mm Hex Nuts	Home Depot	26	$0.07	$1.82
Angled Iron	Lowe's	1	$8.99	$8.99
		Total Cost:		$265.75

Table 7: Bill of Materials

Other expenses were incurred due to the testing of various designs of designs and powering systems. The list of all expenses throughout the course of the project are listed below in Table 8.

Item Description	Supplier	Quantity	Cost per Item	Total Cost
1" PVC EL 90D SXS	THE HOME DEPOT	18	$1.14	$20.52
1" PVC TEE SXSXS	THE HOME DEPOT	30	$1.34	$40.20
8OZ PVC CEMENT REGULAR CLEAR	THE HOME DEPOT	1	$3.63	$3.63
2" X 2" PVC-PW/DWV SCH40 PIPE	THE HOME DEPOT	1	$3.98	$3.98
1" X 10' PVC40 PE PIPE	THE HOME DEPOT	6	$3.33	$19.98
2x4-84" Prime KD Whitewood Stud	THE HOME DEPOT	9	$2.34	$21.06
5Gal Homer Bucket	THE HOME DEPOT	1	$3.25	$3.25
3" Construction Screw 1 lb.	THE HOME DEPOT	1	$8.47	$8.47
50lb Quikrete Fast Setting Concrete	THE HOME DEPOT	1	$5.48	$5.48
Stanley 25' x 1" Powerlock Tape Msre	THE HOME DEPOT	1	$9.88	$9.88
1-1/4" PVC Ball Valve FPT SCH40	THE HOME DEPOT	1	$5.51	$5.51
Filler Gal	WALMART	1	$15.44	$15.44
Alex Fst Dry	WALMART	1	$2.47	$2.47
Loc 12oz TI	WALMART	1	$5.88	$5.88
5QT Pail	WALMART	1	$2.47	$2.47

Smooth Hex Rod Caulk Gun 10 0z	THE HOME DEPOT	1	$5.97	$5.97
HDX Blue Nitrile Disp Glove 10pk	THE HOME DEPOT	1	$2.48	$2.48
GE Silicone II W&D Clear 10.1 oz.	THE HOME DEPOT	7	$5.92	$41.44
Hinge, Dr 4" Square Sn	THE HOME DEPOT	1	$2.98	$2.98
Pack and Seal Box, Medium	THE HOME DEPOT	1	$2.98	$2.98
Lock Nut Nylon Zinc 1/2" - 13	THE HOME DEPOT	1	$1.18	$1.18
1" PVC Cap Slip	THE HOME DEPOT	11	$0.83	$9.13
Hex Bolt 1/2x2	THE HOME DEPOT	1	$0.58	$0.58
Kobalt 1/2 in dr 1-1/4 in	LOWE'S	1	$6.98	$6.98
5/16 in Hex Nut 18 G 5-CT	LOWE'S	1	$1.09	$1.09
HM 1-CT 5/16 in x 1/2 in HX	LOWE'S	1	$0.15	$0.15
Leg 2500-6600 Plastic LMP	LOWE'S	1	$1.38	$1.38
Gas Leak Detection Solo 2	LOWE'S	1	$2.38	$2.38
Hex Nut Zinc 1/4"	THE HOME DEPOT	1	$1.18	$1.18
Hex Bolts 1/4 x 2-1/2	THE HOME DEPOT	23	$0.22	$5.06
Hex Bolts 1/4 x 2	THE HOME DEPOT	3	$0.20	$0.60
Hex Bolt 1/4 x 1-1/2	THE HOME DEPOT	3	$0.19	$0.57
Rod Threaded SS 36x1/4-20	THE HOME DEPOT	1	$5.24	$5.24
Flex Seal Liquid 1 Qt Black	THE HOME DEPOT	1	$29.98	$29.98
Everbilt 1/2 in. x 72 in. Plain Steel Square Tube with 1/16 in. Thickness	THE HOME DEPOT	12	$11.22	$134.64
2" Gold Screw 1 LB	THE HOME DEPOT	1	$4.77	$4.77
Hex Bolts 1/4x3	THE HOME DEPOT	4	$0.24	$0.96
1/4-20"x4" Hex Bolt AP	THE HOME DEPOT	4	$0.28	$1.12
Hex Nuts-USS 1/4	THE HOME DEPOT	12	$0.07	$0.84
Hex Nuts-USS 1/4 - 100PK	THE HOME DEPOT	1	$5.95	$5.95
6in All Thread 1/4 in (CT1)	LOWE'S	6	$0.96	$5.76
2-in x 5-ft sch40 pipe	LOWE'S	1	$6.06	$6.06
1/8-in x 3-ft Angle Iron	LOWE’S	3	$8.99	$26.97
¼-in x 2-in Hex Bolts	LOWE’S	4	$0.67	$2.68
Welding Gloves	LOWE’S	1	$10.48	$10.48
3/32-in Milwaukee Titanium SW	HOME DEPOT	1	$3.77	$3.77
Milawaukee 1” Bi-Metal Holesaw	HOME DEPOT	1	$9.97	$9.97
Foam core Poster	Printing Services	1	$65.48	$65.48

Table 8: Actual Cost of Materials

The frame resulted in most of the expenses, totaling $152.70. This is due to the cost of the material that was used. The remaining expenses were from purchasing materials necessary to build multiple configurations of the agitation device, the preliminary frame design, and the final frame design. A breakdown of expenses by category is shown in Table 9.

Expenses by Category	Cost
Agitator/Hand Crank	$135.89
Mold Testing	$108.18
Frame	$152.70
Equipment and Misc.	$135.91

Table 9: Project Expenses

The total amount of expenses incurred, and the remaining budget is shown in Table 10.

Total Funds	$1,000.00
Total Expenses	$532.68
Remaining Funds	$467.32

Table 10: Budget

This project was kept well under budget with a remaining balance of $467.32. This is due to the donations of materials and services. Welding of the final frame was estimated to be $75.00 an hour and the welding job took a total of 5 hours. Additionally, both the preliminary and final drums that were used were donated. Total savings due to these donations can be seen below in Table 11.

Item Description	Cost
Plastic Drum	$71.00
Steel Drum	$94.00
Welding	$375.00
Total:	$540.00

Table 11: Donations

5 ENGINEERING ANALYSIS

Material Selection:

The materials available in Malawi are very limited when compared to the United States, where the design is being completed. The materials chosen for the final design need to not only satisfy the requirements for the machine, but they need to be readily available in the country of Malawi. This greatly influenced the entire design process. While the design consists predominantly of two materials, steel and PVC, the likelihood of material failure was higher in any part involving the PVC. The critical agitation shaft, for instance, was given additional attention because the PVC was much weaker than the other materials surrounding it, such as steel. When pushed to the breaking limit, the PVC parts would be first to fail.

Size differences (in to mm):

The machine was designed in the United States with Standard units while Malawi uses Metric units. While it may seem counterintuitive, this helped simplify construction and testing. The main parts affected by this change include any PVC pieces, bolts, and nuts. One inch (25.4 mm) and two inch (50.8 mm) PVC pieces were used during construction for testing. The PVC dimensions that are available in Malawi are 25 mm and 55 mm. This difference is considered negligable for the uses in the washing machine. The holes that acommidate the two inch PVC at either end of the drum can simply be changed to match the metric equivalent of 55 mm.

The bolts and nuts are also easily interchangable. Due to their abundance, quarter-inch bolts and nuts were chosen for the design of the agitator and it's components. There is no design constraint that limits the size, larger or smaller, so any bolt is considered interchangeable as long as it fits within the PVC. As long as the hole can be drilled through the PVC, any bolt and corresponding nut will suffice.

The other main components of the design, such as the drum or tubing, do not have any conflict with the difference in units. Similar to the PVC availability, the tubing is available in a variety sizes, meaning its use will not limit the construction. The drum is similarly available in Malawi.

Original Finite Element Analysis:

During the design phase in which the agitation source was still being investigated, a finite element analysis (FEA) code was written to determine if a particular agitator was viable. The code can be found in Appendix B. The code was originally run for an agitator that had a thickness of two inches. The results showed that the agitator was perfectly capable of withstanding the forces it would be subjected to. This then allowed the team to further the deveopment of the agitation device using this particular design.

Mold Tolerances:

The molding process underwent many iterations before the pursuit of other options. Some major issues with the mold were the tolerance for the mold itself and the tolerance of the final part. Many of the mold iterations were too porous, leaving defects in the final mold; these defects left the teeth with unsatisfactory dimensions. A solution was discovered in the method of curing a sillicone mold in layers. Though this remedied the tolerance difficulties, it caused a significant defect at mold layers, where separation points occurred at the layer boundary. If any force caused the mold to bend or deform, the layers would separate from each other, destroying the mold. Faced with these difficulties, the engineering decision was made to seek an alternative method for power transmission.

Bending of Threaded Rods:

Since the mold for the ratchet was infeasible, a replacement ratchet became necessary. The solution came in the form of a PVC pipe with threaded rods going through the tube at specific increments. There are two crucial aspects in this design's success: teeth impact and hole alignment. First, the driving pawl needs to impact two teeth simultaneously to prevent any unwanted torsion. While this idea prevented twisting and bending, it introduced problems with hole alignment. The holes for the threaded rod had to be drilled exactly in line with another to ensure that both teeth contacted the pawl at the same time. While not impossible, this would be very difficult to perform with limited tools and experience.

The teeth in this ratchet would receive the full power of the operator with every stroke, meaning that they were prone to fatigue and power related issues. One concern is plastic deformation. On a stress-strain curve, there exists a region of deflection such that the material will return to original shape after the load is removed. While the force required to spin the agitator is high, it is not enough to permanently bend the teeth, though repeated force over time may cause bending.

Hand Crank and Drum Height:

Because the power transmission system was inefficient, an alternate needed to be developed. The solution came in the form of a hand crank created out of PVC pipes and fittings. Said crank allowed for a direct power input to the machine, which greatly improves the ability to communicate the design. However, the crank needs to be a comfortable level off the ground for the crank to be viable, meaning the drum and the frame will have to be raised. The length of the lever arm on the hand crank also requires adjustment to be comfortable for the operator. These restrictions are accounted through the variabilty in tubing length. To find a suitable crank height, all team members used the crank with different lengths to determind an appropriate lever arm.

Agitator Angular Deflection:

Since the agitator will resist the hand crank spinning, a shear force will occur. The shear will cause angular deflection in the connector between the hand crank and the agitator. The force required to spin the agitator will not cause a significant amount of angular deflection, and, because the lengths involved and forces present are small, it was determined that angular deflection would not be a problem in this design. It was also determined that PVC glue would fail in shear before a bolt would. Therefore, the PVC was attached to the hand crank with a bolt, allowing for a more modular design.

Agitator Deflection Inside the Drum:

Since the agitator is fixed on each end, it can be modeled in three-point-bending. The weight of the agitator is considered as a point load directly in the middle of the shaft, causing deflection. This deflection is critical and needs to be accounted for when designing the length of the fins. The fins need to be long enough to catch any clothes that are soaking at the bottom of the drum but short enough to avoid interfering with the drums inner surface. A gap of approximately half an inch was determined to be the optimal distance for the agitator’s operation.

Draining:

The drum will need to be drained once the clothes are cleaned. Four draining possibilites were investigated by testing the overall sealing and draining capabilities of each of the four options. Coupled with the difficulty of communication and manufacturing time, the decision to utilize the bunghole over other methods was made based upon the overall ease it provides. It already forms a firm seal over the drum and allows most of the remaining water to be dumped out. If needed, the syphon and bulkhead fittings can be used if the bunghole is not usable for any given reason.

Failure:

One important consideration in the design was determining where the machine is most likely to fail. The highest chance of failure occurs at the connection between the hand crank and the agitator. Calculations preformed showed the PVC at this point has a factor of safety of five. This failure, while unlikely, could still occur. This was remedied by the inclusion of a bolt connecting the two parts, which increased the safety factor to approximately forty. This connection allows for either part to be replaced in the event of failure.

6 CONSTRUCTION/PROTOTYPE

An important aspect of this project was that the washing machine needs to be built entirely in Malawi. Therefore, for any part or tool that was used to create the prototype washing machine, there must be an equivalent part or tool present in Malawi.

For the prototype washing machine, a 55-gallon drum was used as the main body, and half inch steel tubing for the frame. The frame (shown in Figure 21) was constructed using an acetylene torch to cut the tubing, a plasma cutter to cut the drum, and a MiG (Metal inert Gas) welding gun to weld the tubing together.

Figure 21: Welded Metal Frame

Two-inch diameter holes were cut in each end of the drum for the agitator to pass through and, a thirteen-inch by six-inch hole in the top of the drum was cut to load and unload clothes. Two bolts were welded to the frame, with threads pointed up, so that the head of the bolts was the connection point. These bolts were at each end of the drum but offset to allow the PVC bearings to be properly aligned with the holes cut in the drum. The PVC bearings were then attached to the bolts and using nuts, tightened into place. The completed drum and frame assembly is shown in Figure 22.

Figure 22: Drum and Frame Assembly

The Bi-Fin agitator was assembled using two consecutive parallel pipes connected with elbows as fins. Four fins were then oriented at ninety-degrees relative to the adjacent fin and bolted into place (Figure 23). The fins were glued in place to remove the now-unnecessary bolts. The Bi-Fin agitator was inserted into the drum through the top hole.

Figure 23: Bi-Fin Agitator Assembly

The support tail was led through two PVC bearings and into the drum and bolted to the agitator. The end of the support tail was then capped to restrict lateral movement. The hand crank was assembled by connecting PVC pipes by elbows and T-joints in an L-shape. The long end of the crank was led through the other two PVC bearings, into the drum, and bolted into the agitator as seen in Figure 24.

Figure 24: Washing Machine Final Assembly

7 TESTING AND VALIDATION

Mold Testing

The mold was evaluated based on the time necessary for the mold to set and the accuracy of the mold. Initially, the mold was constructed out of Bondo. Unfortunately, the Bondo latched onto the molding piece too strongly, to the point where they could not be separated. As a result, a silicone mold was investigated instead. Initially using silicone and cornstarch, a mold of the ratchet was created. The pieces were easily separated, though the formula used resulted in incredibly thick material which was difficult to use in accurately shaping the mold.

The accuracy and workability of the silicone was promising, so different formulas were investigated to improve the workability. Instead of cornstarch, hand soap was used, resulting in easy workability and a runny consistency. It was a little too runny, so adding cornstarch alongside the hand soap to thicken the material was investigated. Three samples were created: one with little cornstarch, one with some cornstarch, and one with a large amount of cornstarch. Each was used on the same object and started at the same time. The molds took more than one month to properly set, meaning none could fit in the initial time constraint, necessitating a different construction method or different design for the gear.

Agitator Testing

Each agitator was built and evaluated on four criteria: Agitation, Ease of Construction, Weight, and Communicability. Each fin was rated on a scale of one to five for each of the criterion on Table 12 shown below. For the Agitation, the Mono-Fin was given a two due to the tendency for the sheets to wrap around the central axis instead of continuously being moved in and out of the water. This problem slightly occurred in the Bi-Fin agitator. However, most of the sheets were repeatedly dunked in the water, thus cleaning the sheets well. Therefore, the Bi-Fin agitator was given a four. The Tri-Fin agitator did not experience any wrapping and was given a five.

The agitators were then evaluated on their ease of construction. Since the Mono-Fin did not require any precise angles or for a particular orientation, it was given a five. The Bi-Fin was similarly easy to build and was also given a five. The Tri-Fin agitator was significantly harder to build than the other two agitators, due to the three non-sequential segments needed to be directly in line to form one fin. Additionally, each of the fins needed to be approximately one hundred twenty degrees from the others. Because of this difficulty, the Tri-Fin was given a one.

Another factor taken into consideration in determining the agitator was weight. Since weight would play a factor in the operation of the washing machine, each agitator was weighed and ranked. The Mono and Bi-Fins were very close in weight, with the Mono-Fin being less than a tenth of a pound lighter, thus they were both given fives. The Tri-Fin was more than a pound heavier than the other two, therefore it was given a two.

Lastly, the fins were evaluated on their communicability. Since the washing machine is to be built by people that likely cannot read, it must be easy to construct the washing machine from pictorial representations alone. The Mono-Fin agitator was the easiest to communicate since there was no particular orientation of fins. Due to this, the Mono-Fin was given a five. The Bi-Fin was not much harder to communicate and was given a four. Because of the Tri-Fin's precise orientation and organization it was the most difficult to communicate and given a one.

As the table below shows, the Bi-Fin agitator is the best all-around agitator for the purposes of this project, thus it was selected for use in the Malawi Washing Machine.

Agitator Comparisons			
Fin	**Mono-Fin**	**Bi-Fin**	**Tri-Fin**
Agitation	2	4	5
Ease of Construction	5	5	1
Weight	5	5	2
Communicability	5	4	1
Total	17	18	9

Table 12: Agitator Comparisons

Bending Test

Due to the design, the agitator is held in place at both ends but allowed to rotate freely (Figure 25). Therefore, in order to determine how much weight can be supported by the PVC a bending test was performed. To simulate the design, the ends were held in place and a weight was suspended in the middle of the PVC (Figure 26). The section of PVC was 54" with a weight suspended at approximately 27". The weight used ranged from 1.25-30 lbs., and the PVC deflection was measured.

The test determined that as the load applied to the PVC increased, so did the deflection. Furthermore, the PVC did was not plastically deformed from the load. This confirms that using an agitator with smaller sections of PVC pipe and a lighter load should resist plastic deformation. The data from the test is recorded in Table 13.

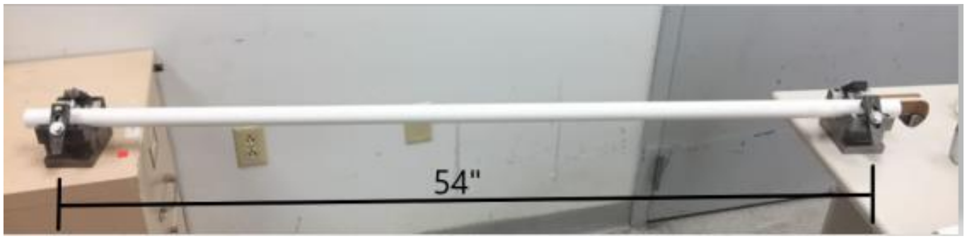

Figure 25: Bending Test Pre-Weights

Figure 26: Bending Test with Weights

Bending Test	
Weight (lbs.)	Estimated Bend (in.)
1.25	0
5	0.25
10	0.625
15	0.875
20	1.5
25	1.625
30	2.25

Table 13: Bending Test Data

Torque Test

Another concern with the PVC agitator was that the threaded rods used for the ratchet could shear through the PVC. To test this, a rig (shown below in Figure 27) was constructed. The rig was made of a PVC tube with a threaded rod drilled through the center. Weights were placed on one end of the rod to find both the angular deflection and torque on the PVC. The weights were increased by intervals of ten pounds, and the data was recorded in Table 14.

Figure 27: Torque Test on PVC

Torque Test		
Load (lbs.)	Angular Deflection (Degrees)	Torque (ft*lbs.)
10	0.25	0.859
20	1	2.34
30	2	3.52
40	2.5	5.94
50	3	6.90

Table 14: Torque Test Data

The data was then plotted to show the change in torque and angular deflection as shown in Figures 28 and 29.

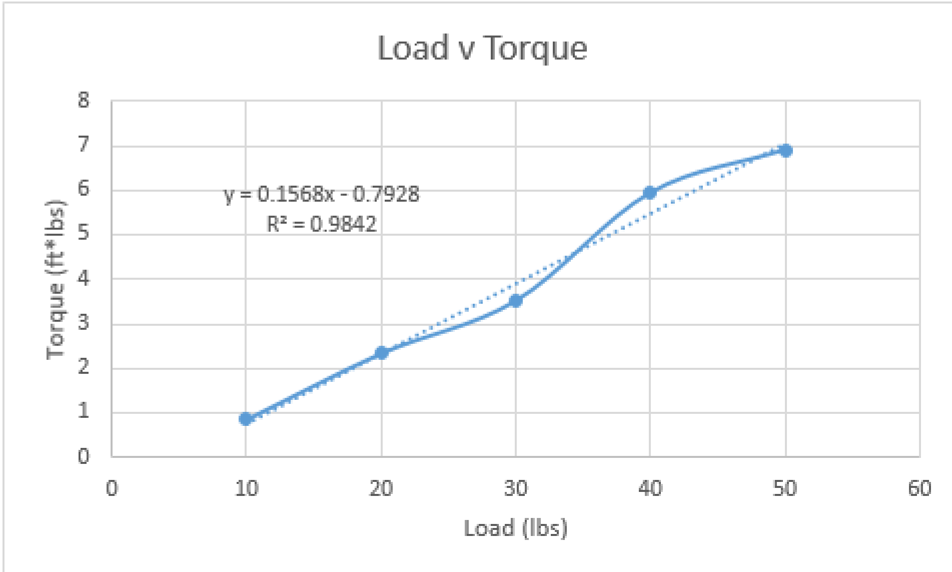

Figure 28: Plot of Load V Torque

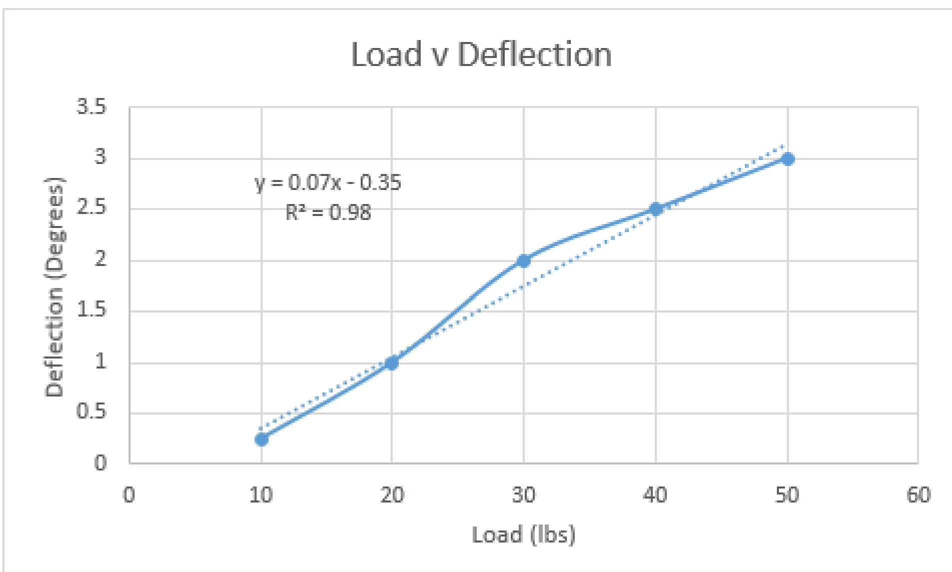

Figure 29: Plot of Load V Deflection

After the torque and angular deflection tests were performed, the maximum number of weights that would fit were placed on the rod to see if the PVC would fail (Figure 30). Even after ninety pounds of force were applied to the PVC, the section of PVC was not deformed, showing that the ratchet is not susceptible to fail by shearing the PVC.

Figure 30: Failure Test

Drainage Testing:

For the drum draining, a decision matrix was created to determine the optimal draining solution. Four solutions were investigated: a syphon, a bulkhead fitting, a flap, and a bunghole. The flap would use the weight of the water to form a seal around a hole in the drum. It could be placed on the curved bottom surface for a larger hole, allowing for the best possible drainage of all options. Unfortunately, the seal was lacking, and the time to improve the seal was minimal, so different solutions were necessary. The syphon would be more difficult to use for draining but would require minimal manufacturing time since only a hose is needed. The bulkhead would offer better draining potential at the cost of more parts and complexity. Both of these methods are equivalently viable, and one can be selected based upon availability within the country. However, the best solution is the bunghole already present on the drum. It requires no additional manufacturing and offers a strong seal. If no bunghole is present, or the bunghole cannot be used for some reason, then either the bulkhead fitting or the syphon can be considered. The Drainage Decision Matrix is shown in Table 15.

Drainage Decision Matrix				
	Syphon	Bulkhead/Plug	Flap	Bunghole
Expense	2	1	3	3

Draining	1	3	3	3
Seal	3	3	1	3
Manufacturing	3	2	1	3
Total	**9**	**9**	8	12

Table 15: Drainage Decision Matrix

Power Testing:

The power required to move a given number of sheets was determined by placing weights on the crank. The value for the force required to move the crank was known once the applied weights moved the crank. The torque was calculated by multiplying the force and the lever arm. This torque was then used to turn the crank for 30 seconds to find the average rotational speed of the crank. The power is calculated for a varying load of sheets. The data is shown in Table 16.

Number of Sheets	Power (W)
0	2.58
1	4.88
2	8.95
3	10.5
4	12.8
4 + Misc.	21.1

Table 16: Power Required for Sheets

The maximum number of recommended sheets is four, due to the effort required by the operator to maintain the operation. Since operation of the drum is continuous, the difficult in maintaining the force requirement for hand rotation would be difficult above four sheets. This load also used less torque than was tested in the Torque Test, thus reducing the likelihood of the bolts shearing the PVC agitator or hand crank. Based upon the line of best fit, the power required to wash load of four sheets plus miscellaneous clothes was approximately the same as a load of seven sheets. The curve in Figure 31 shows the power increase corresponding to an increased number of sheets.

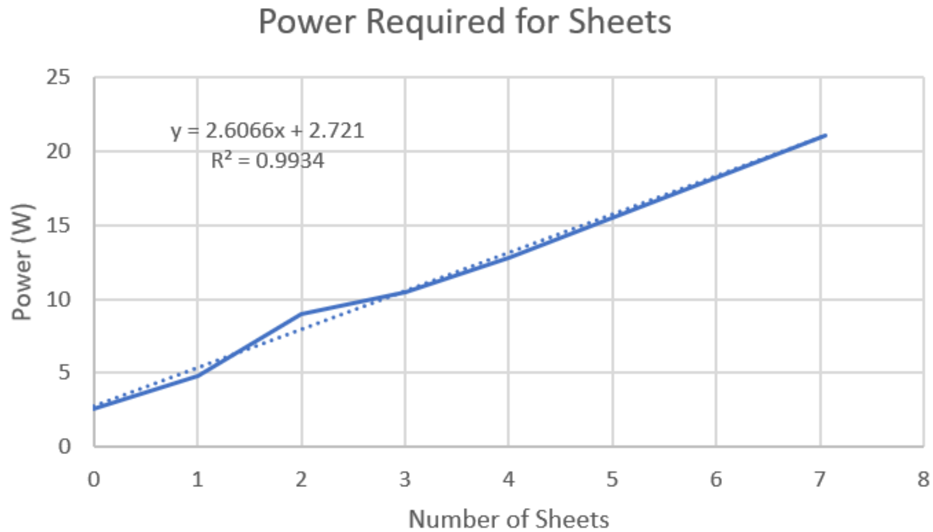

Figure 31: Power Required for Sheets

8 CODES AND STANDARDS

Since this project is being designed in America, and being sent to Malawi, there are not any particular standards that need to be followed. The main goal of this project was to ensure that the washing machine could be built in Malawi from materials and processes available there. One important consideration is the fact that the Metric system is widely used in Malawi. Because of this, all designs were made to have equivalent parts and sizes in both Metric and Imperial systems.

9 PROJECT MANAGEMENT

A list of all tasks including start and end dates are shown in Table 17.

Task	Start Date	End Date	Duration (days)
Research	8/27/18	10/14/18	52
Design Research	8/27/18	9/21/18	26
Patent Research	9/21/18	10/17/18	26
Abstract		9/24/18	
Title Page		9/24/18	
Statement of Work		10/1/18	
Budget & Justification		10/8/18	
Introduction		10/17/18	
Annotated Bibliography		10/22/18	
Approach & Expected Results		10/31/18	

Proposal Draft		11/14/18	
Oral Presentation		11/26/18	
Proposal		12/5/18	
Design	9/27/18	4/10/19	195
Agitator	9/27/18	11/8/18	42
Ratchet/Ratchet Mold	11/8/18	1/13/19	66
Power Delivery	1/13/18	4/3/19	80
Drainage	3/1/19	4/10/19	40
Frame	1/13/19	2/22/18	40
Testing	2/22/19	4/7/19	44
Bending	2/22/19	3/1/19	7
Torque	3/1/19	4/7/19	37
Progress Report		1/28/19	
Codes and Standards		2/11/19	
Progress Report II		3/18/19	
Draft Report		4/10/19	
In Class Presentation		4/15/19	
Final Report		4/26/19	
Public Presentation		4/27/19	

Table 17: Project Timeline

Tasks were assigned early end dates to allow for faults and delays with the project. Most assignments were on schedule and completed in a timely manner, but other tasks such as research or parts of the design exceeded the end dates assigned. Due to the way scheduling was done, this gave plenty of time for the project to completed. The prototype was finished just after it's end date of March 31, 2019 and the ensuing final construction began April 13, 2019 and was set to end April 16, 2019. Final construction ended April 22, 2019 after final touches were made to the washing machine which but the project promptly on time as the tolerance in the schedule allowed for completion up of the project up to April 25, 2019.

Throughout the course of this project, work has been divided amongst team members dependent upon task as can be seen in Table 18.

Task	**Group Member(s)**
Research	All
Design	All
3D CAD Modeling	Jake Erwin, Bradley Franks, & Kyle Wilson
MATLAB Coding	Wesley Eidt, Bradley Franks, & Ryan Kinkade
Testing	All
Construction	All
Communication	Bradley Franks
Budget	Kyle Wilson

Timeline	Kyle Wilson
Meeting Minutes	Ryan Kinkade

Table 18: Division of Labor

For tasks such as research and design, all members were tasked with finding resources and contributing to the brainstorming of design concepts. For other tasks that were more software dependent, members who were deemed more proficient using the software were tasked with the correlated task. For example, Jake Erwin completed most of the 3D CAD modeling due to his ability to adequately use SolidWorks. Administrative tasks such as communication, budget, timeline, and meeting minutes were assigned by member willingness. Bradley Franks volunteered to manage all correspondence pertaining to the project, Ryan Kinkade volunteered to complete weekly meeting minutes, and Kyle Wilson kept track of the budget and timeline of the project.

10 CONCLUSIONS

Through testing and experimentation, a washing machine was designed for processes and materials available in Malawi. The Malawian people are accustomed to making structures and machines for themselves, so working with PVC and welding was not a concern. This made both PVC piping and metal tubing obvious choices for construction.

PVC pipes of various sizes are used to carry a small amount of water from a nearby river to the hospital in Malawi, showing that they have various joints and PVC cement. This made PVC the ideal option for the agitator for the washing machine. The pipes can be oriented in several ways to meet any need and are lightweight enough to be rotated with ease. Several different agitators were tested and evaluated on agitation, weight, communicability, and construction. It was shown that the Bi-Fin agitator preformed the best overall.

Metal tubing was found to be the ideal choice for the frame of the washing machine. Tubing of various sizes is both readily available and strong enough to support a load of laundry and a metal or plastic drum.

The powering system for the washing machine required several iterations to find the most effective option. Various types of molds were tested, with minimal success. Most molds either solidified quickly but showed little detail or showed great detail but took a long time to solidify. Instead of use a mold, a ratchet was built using threaded rods, fixed to a PVC pipe. A stepper was then designed and used to provide force on the ratchet, causing the agitator to spin. However, the torque applied by the stepper was too great and caused some of the threaded rods to bend. A different form of powering was required to operate the washing machine. A hand crank was chosen to connect the agitator, allowing for the torque to be applied directly to the shaft. The hand crank was constructed from PVC since it proved to be strong and would easily attach to the shaft. The crank proved to be very effective and only required a small amount of force to power the washing machine.

The design for the Malawi Washing Machine has proven to be simple to communicate, easy to construct out of available materials, and easy to use over extended periods of time.

11 RECOMENDATIONS FOR FUTURE WORK

Future groups should investigate more efficient draining methods, as the drain designed for this washing machine was limited due to time constraints. Additionally, the height of the machine as well as the agitation geometry could still be optimized. The height of the drum was chosen for a seated position, but it should also be optimized for a standing position. The geometry of the agitator could also serve to be optimized because currrent geometry experiences a lot of tangling around the central shaft and may also catch around bolts which hold the agitator in place. Future groups may seek to optimize these aspects of the decision to create a more efficient design.

12 ACKNOWLEDGEMENTS

A special thanks to Dr. Lynn Rogers and Dr. Bill Wollenhaupt for the donation of a plastic drum and a great amount of advice. Thanks to the Hangartner’s for their advice and information that they provided. Thanks to Mike Erwin for the use of his welding equipment and expertise. Thanks to Kevin Eidt for creating custom metal pieces for the project. And a thank you to Marcus Acton for the donation of a metal drum. Without the help of these individuals, it would have been very difficult to complete this project.

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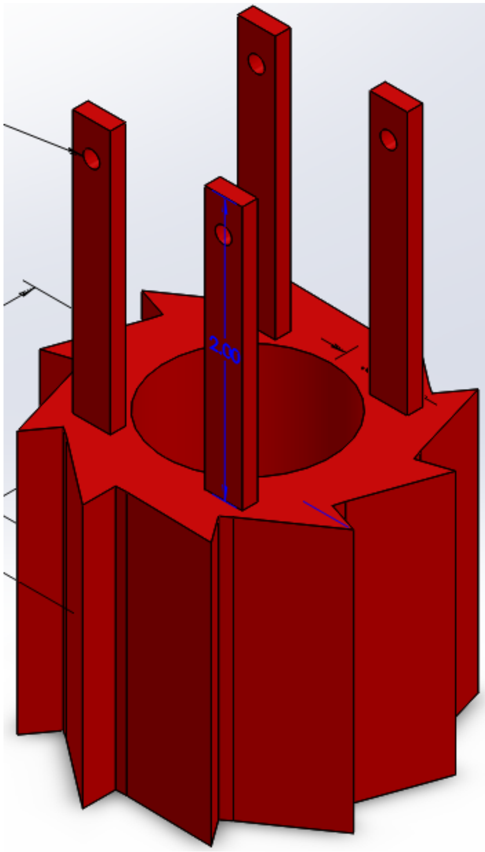
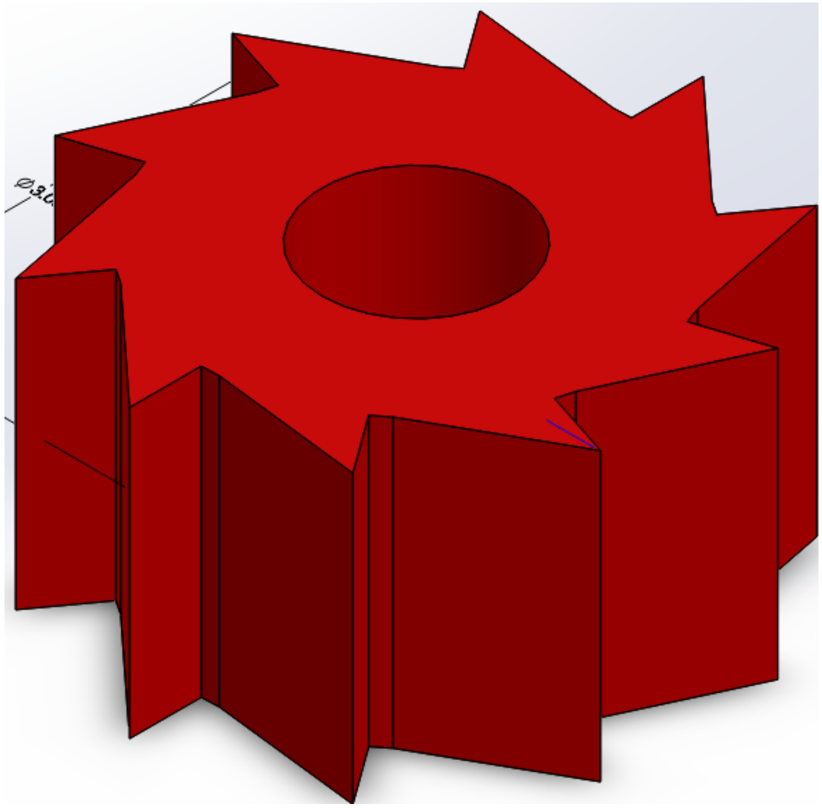
14 APPENDIX A – ENGINEERING DRAWINGS

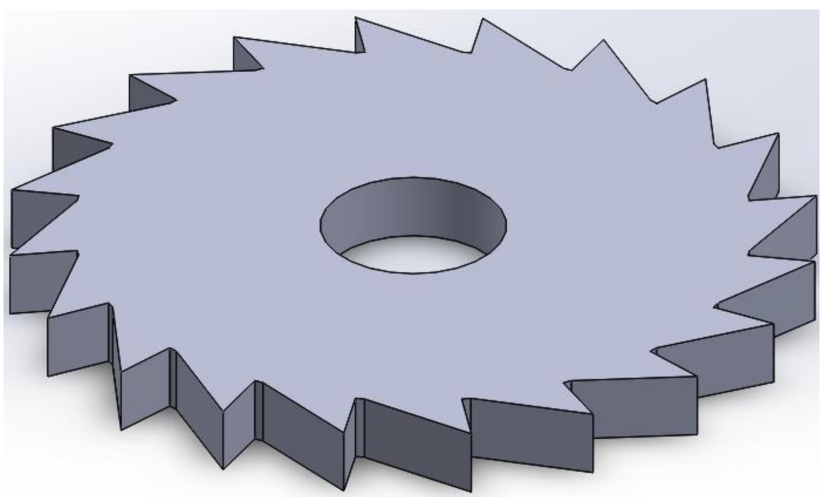
1. Ratchet Model 1



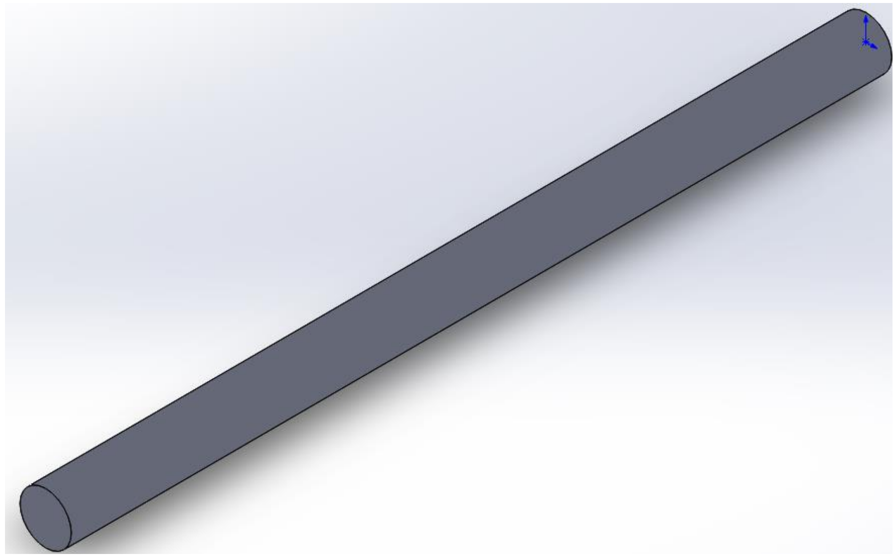
2. Ratchet Model 2



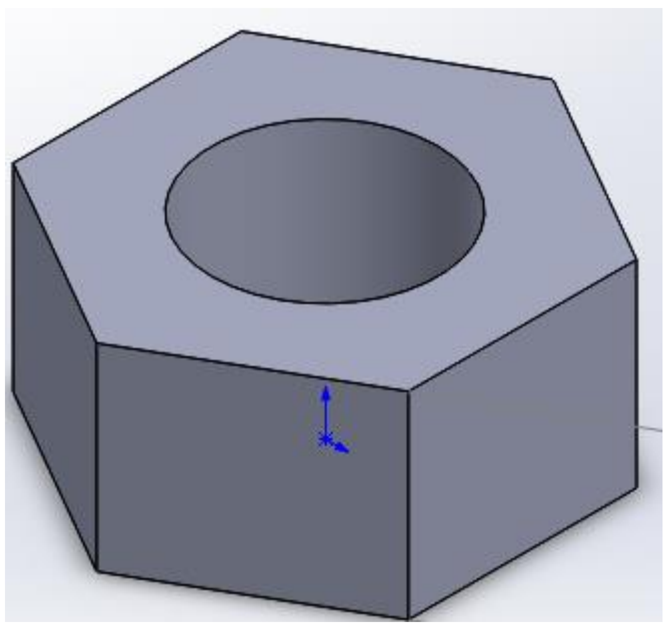
3. Ratchet Model 3



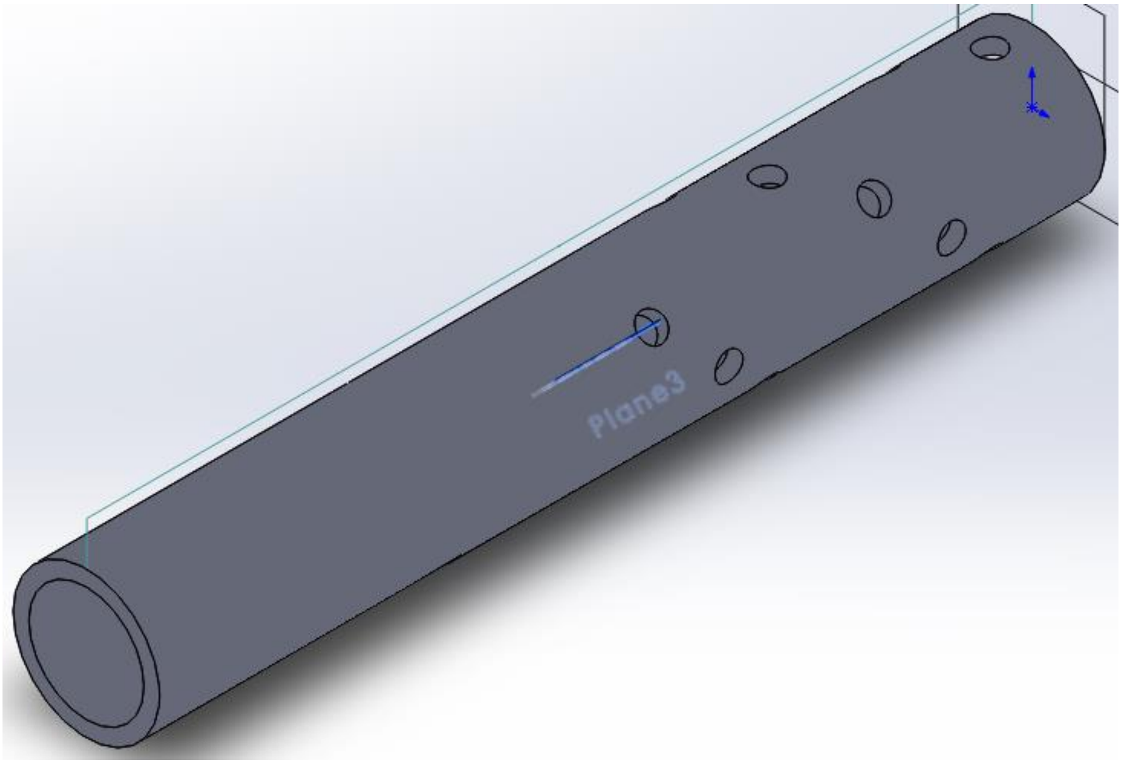
4. 0.25” Threaded Rod



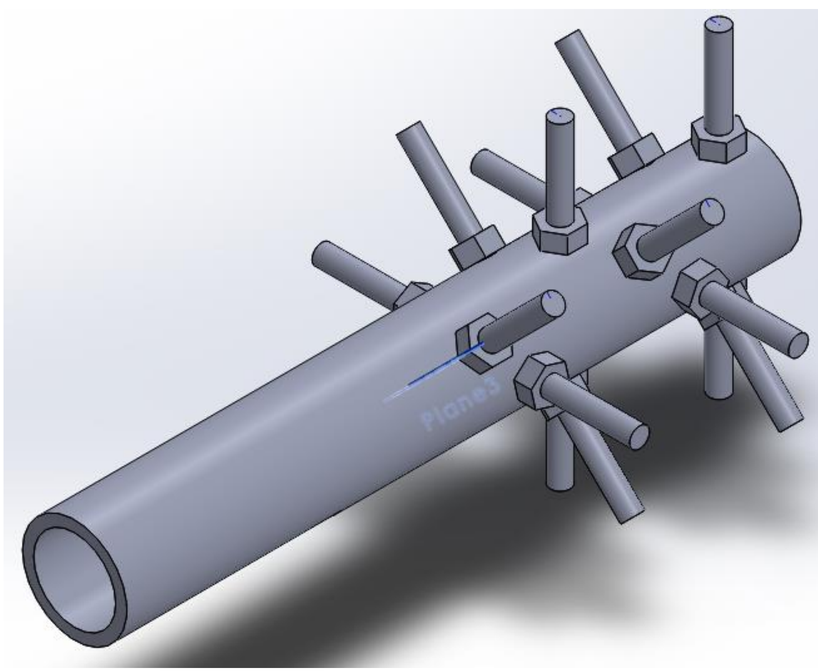
5. 0.25” Nut



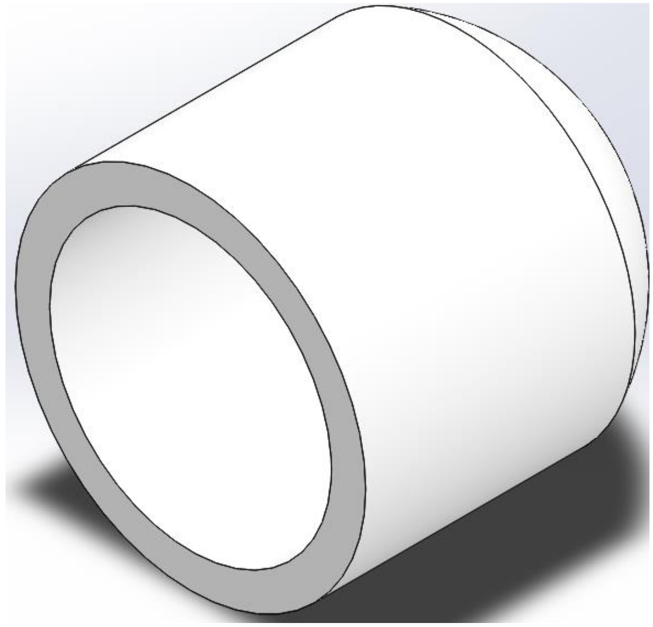
6. 1” Drilled PVC



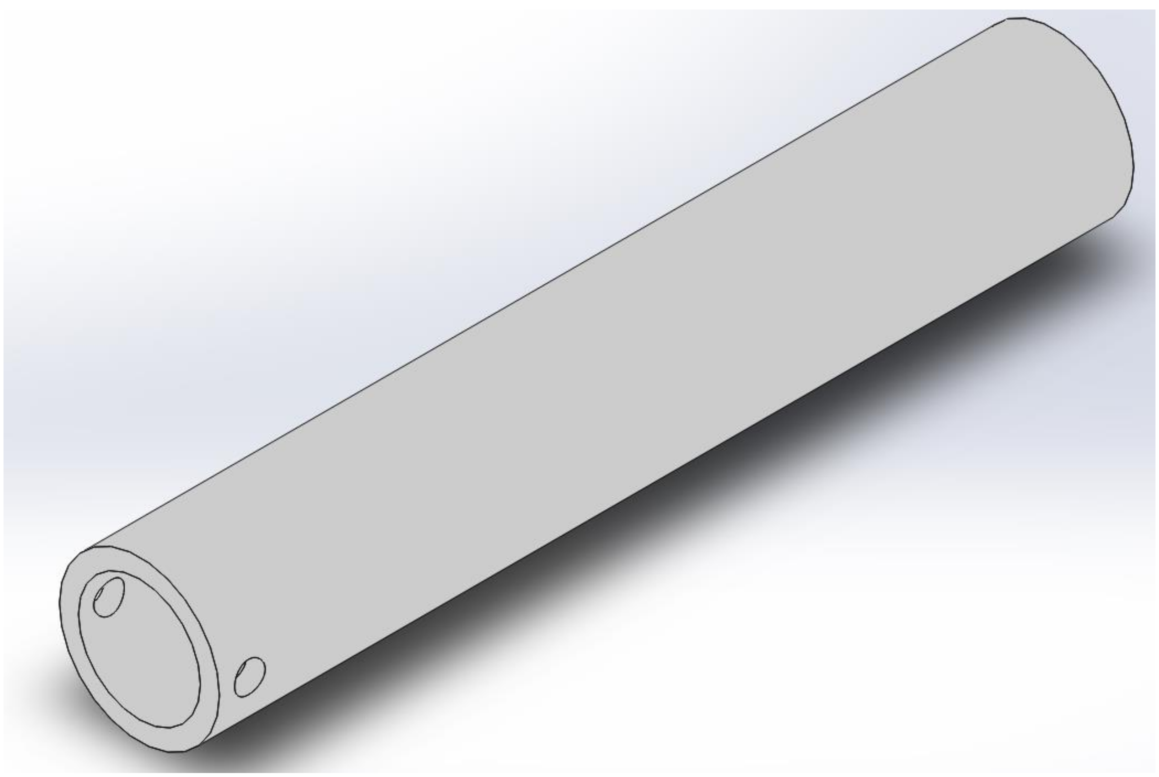
7. Bolt Ratchet



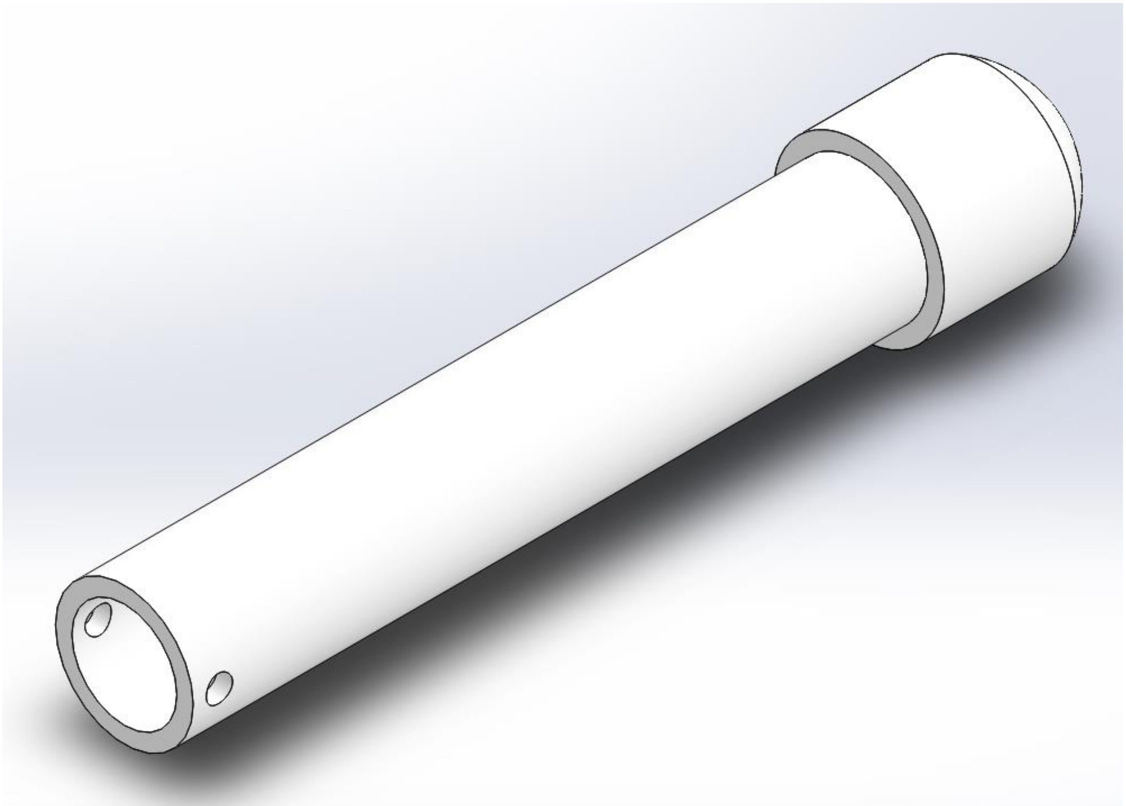
8. 1" PVC Cap



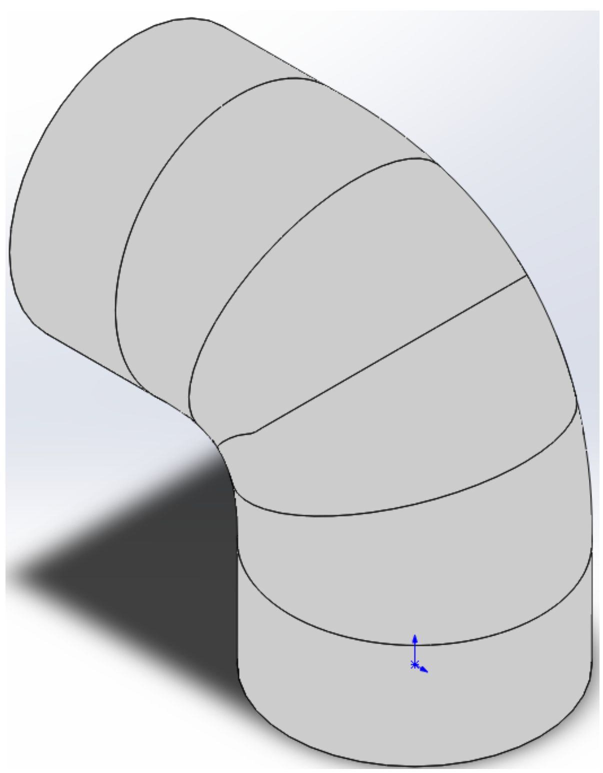
9. 1" PVC Support Tail Pipe



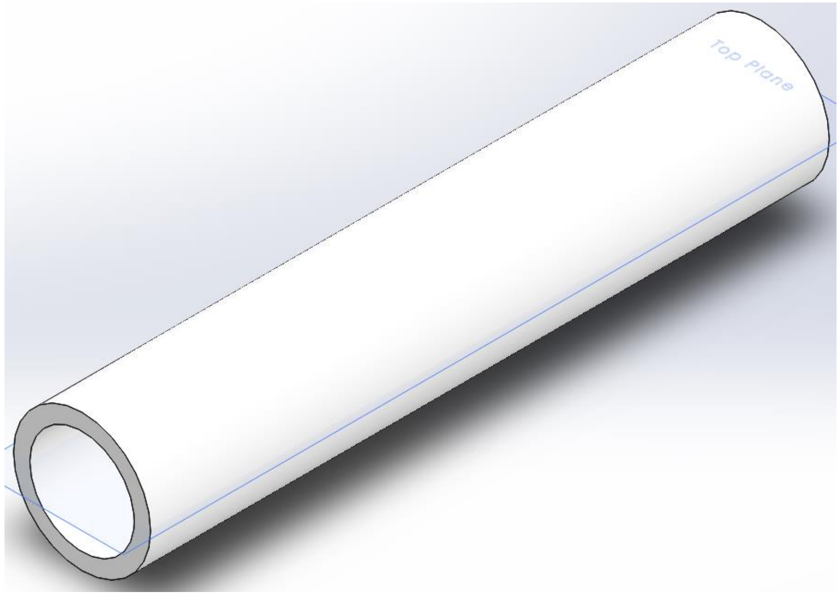
10. PVC Support Tail



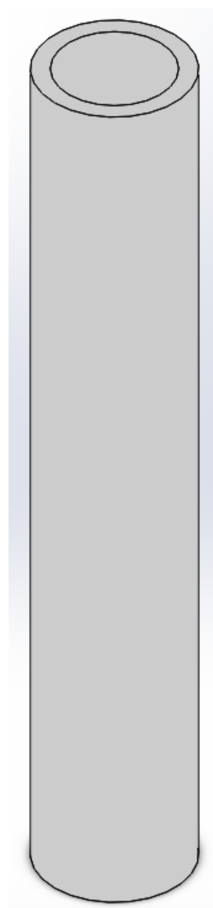
11. 1” PVC Elbow



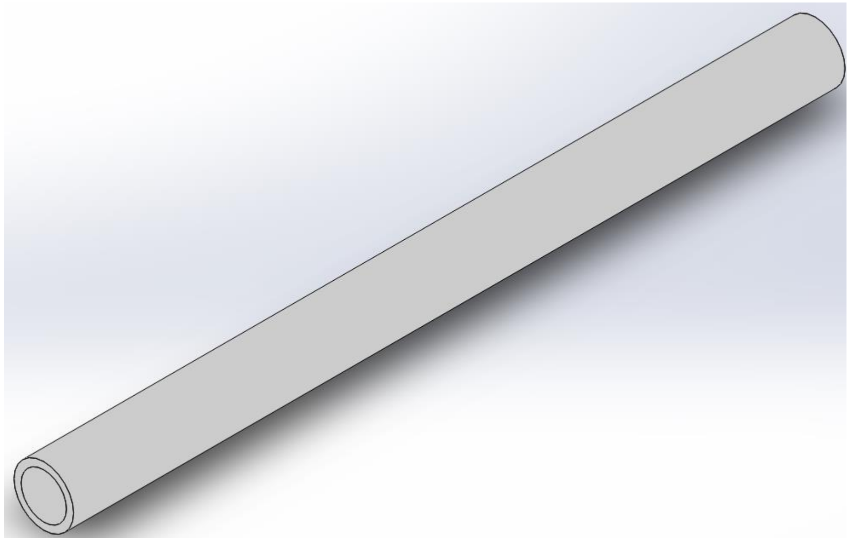
12. 1” PVC Crank Handle



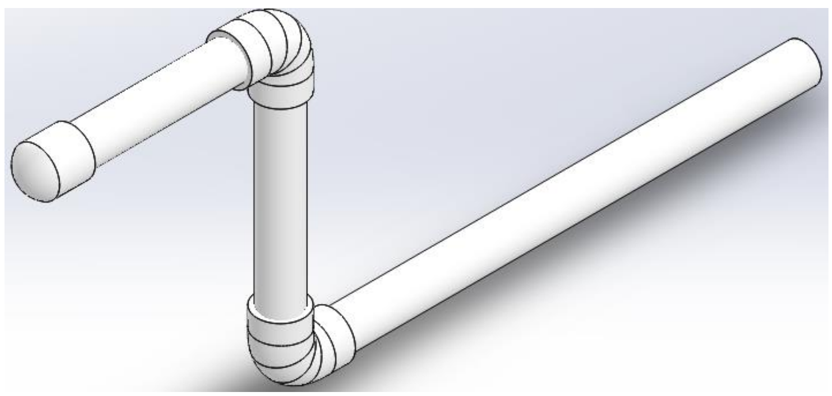
13. 1” PVC Crank Vertical



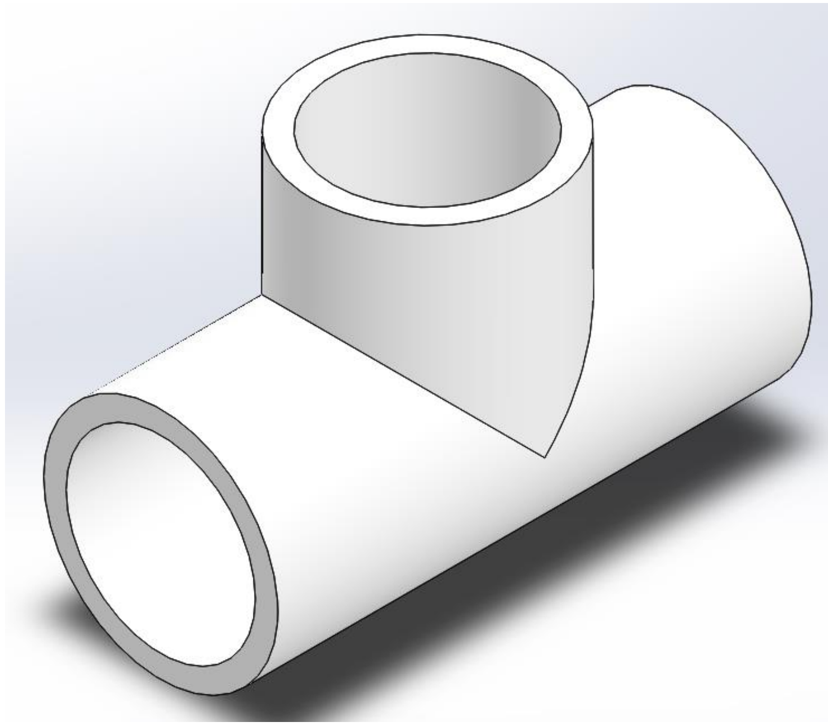
14. 1” PVC Crank Shaft



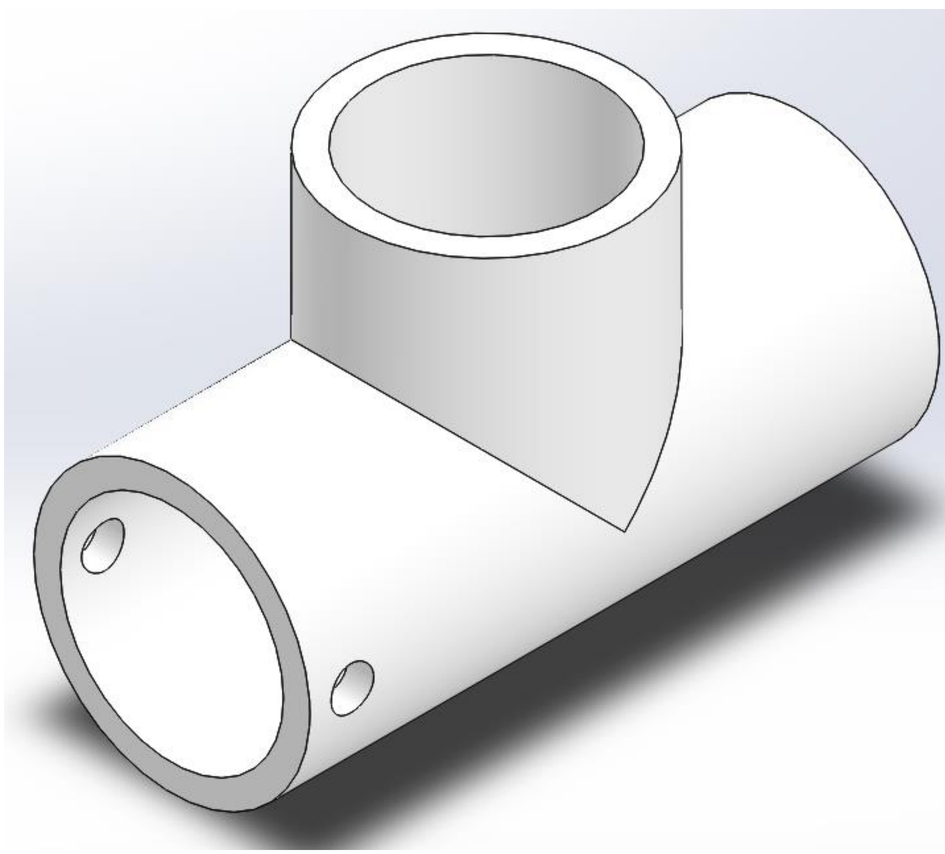
15. PVC Hand Crank



16. 1” PVC T-joint

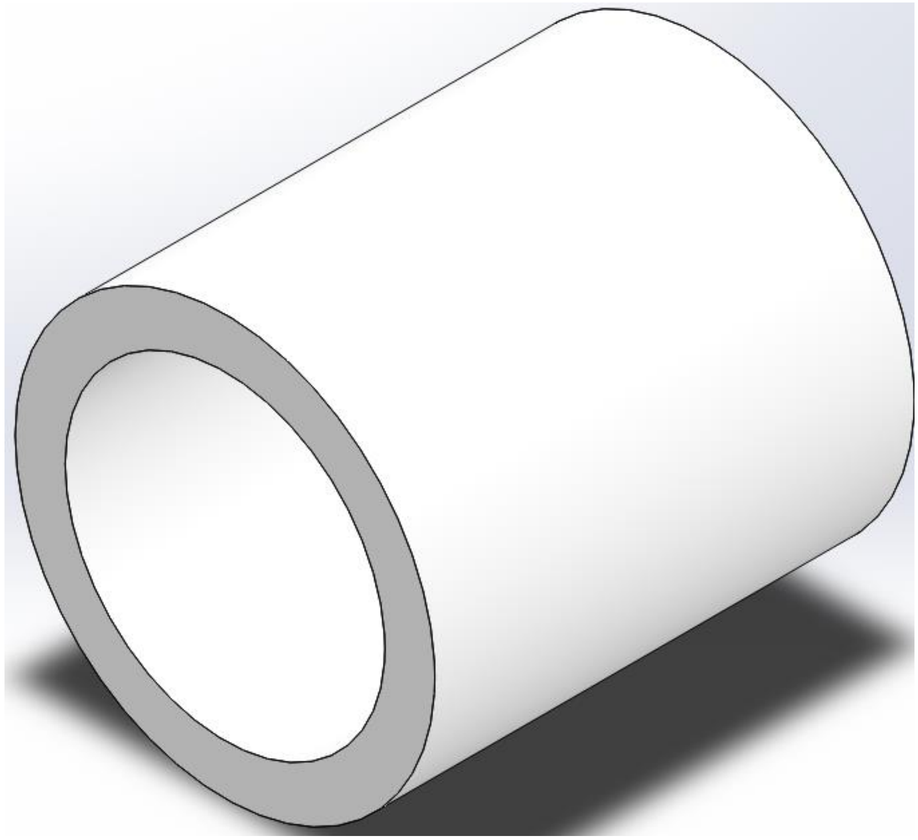


17. 1” PVC T-joint with One Hole

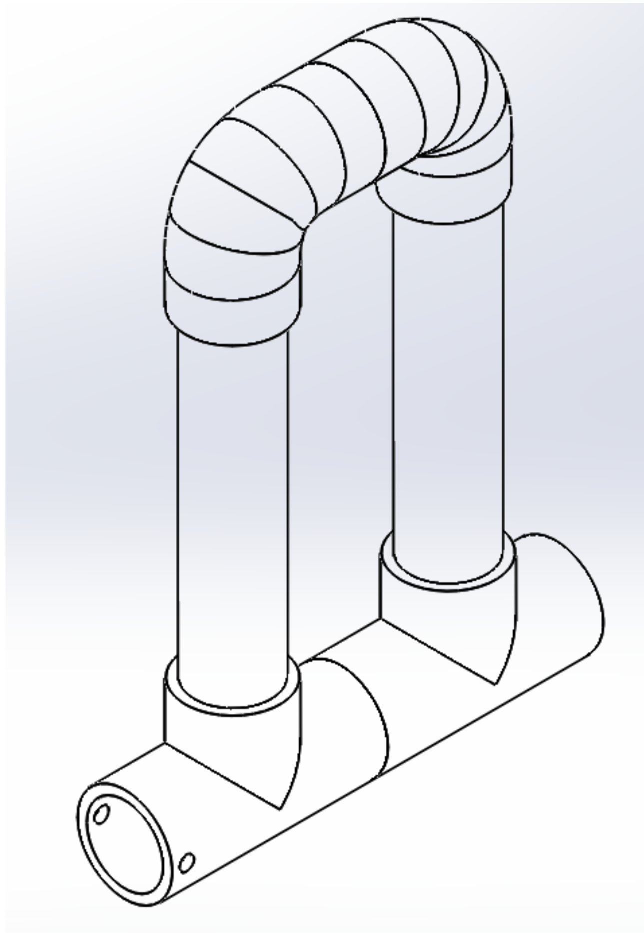


18. 1” PVC Bi-Fin Vertical

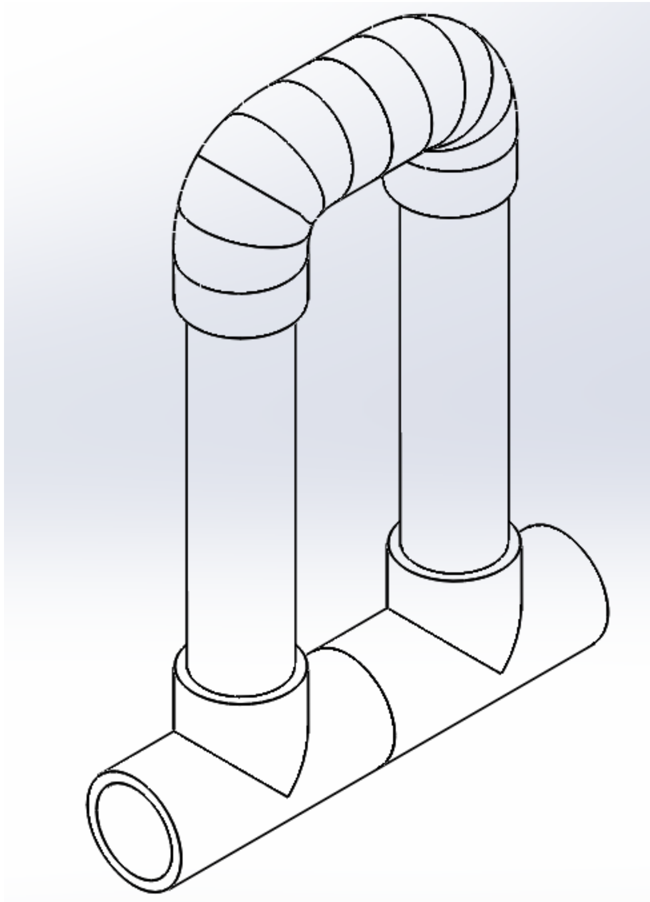
19. 1” PVC Bi-Fin Joiner



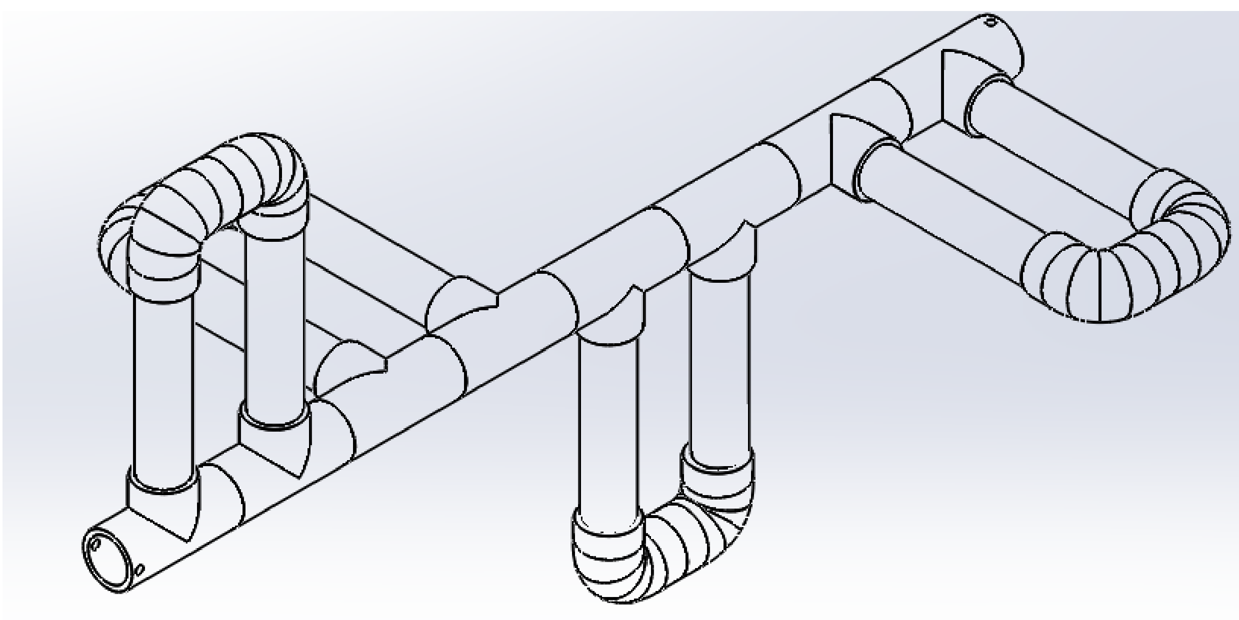
20. PVC Bi-Fin Ends



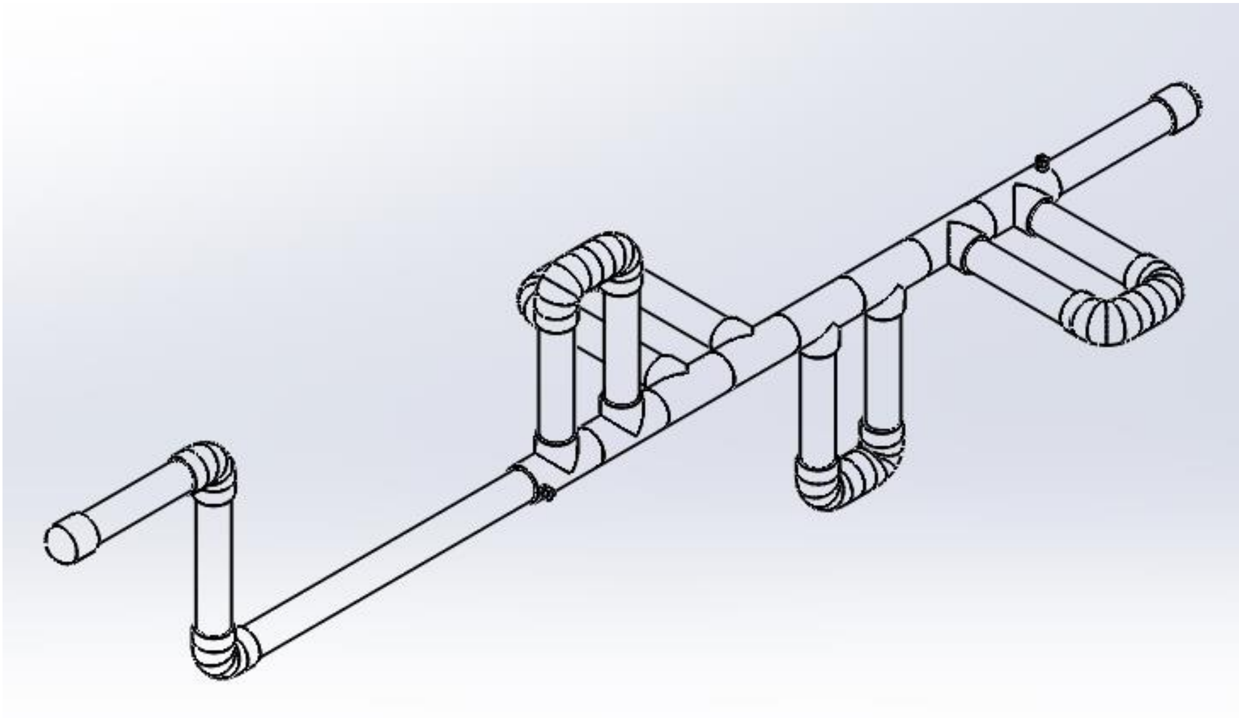
21. PVC Bi-Fin Inside



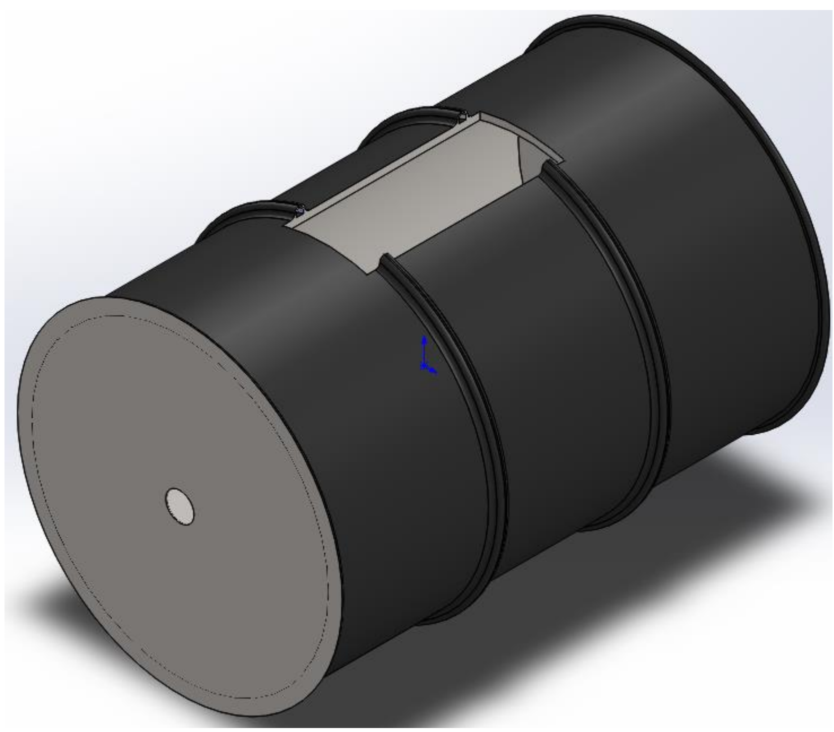
22. PVC Bi-Fin Agitator



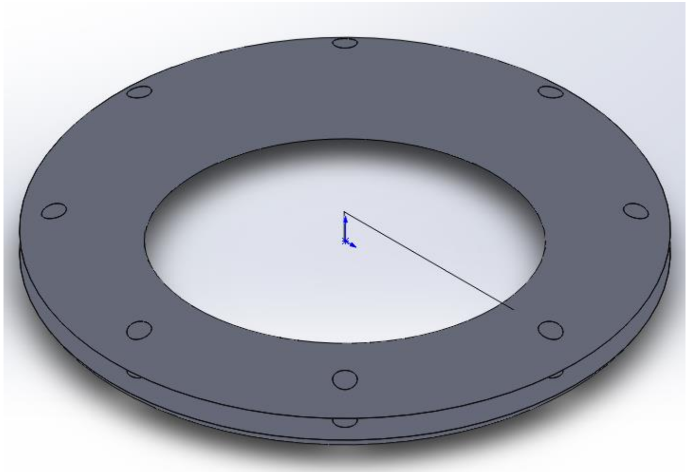
23. Agitator Assembly



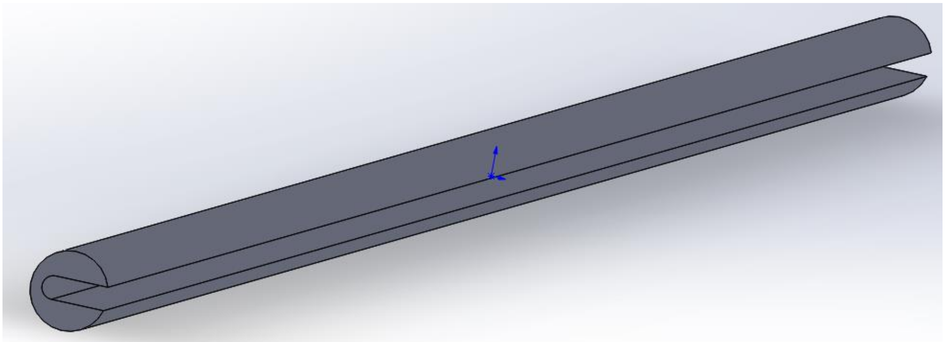
24. Drum



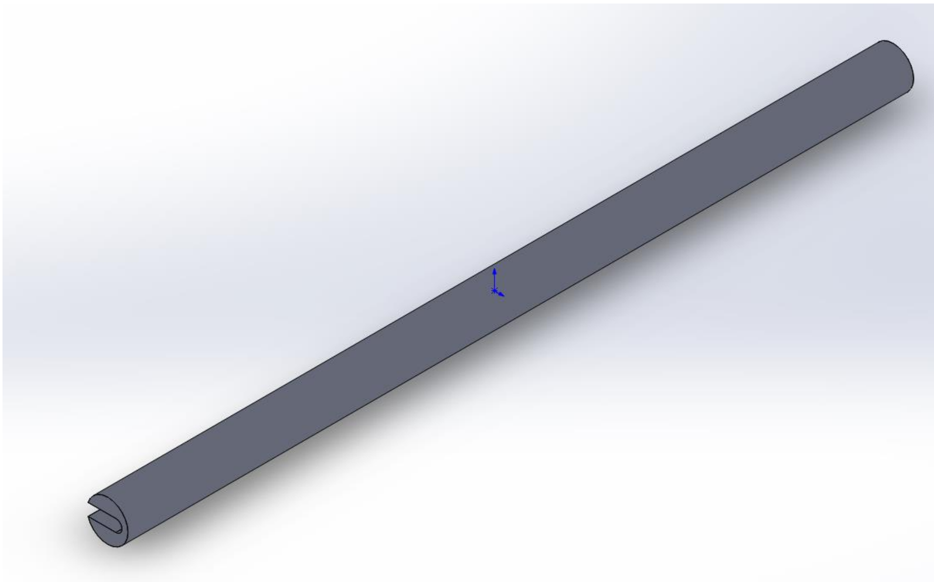
25. Circular Rubber Tubing



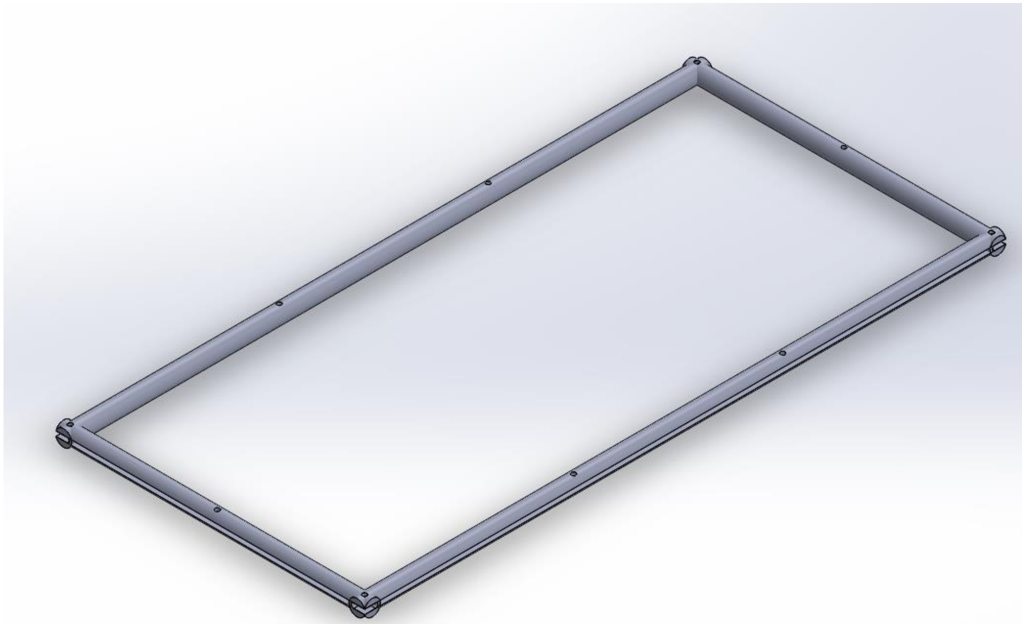
26. Long Rubber Tubing



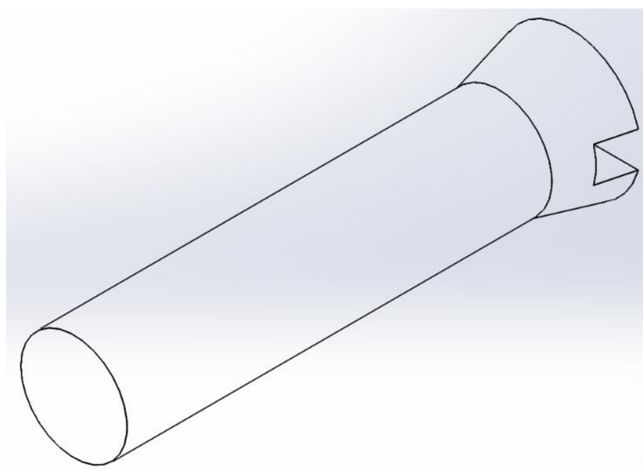
27. Short Rubber Tubing



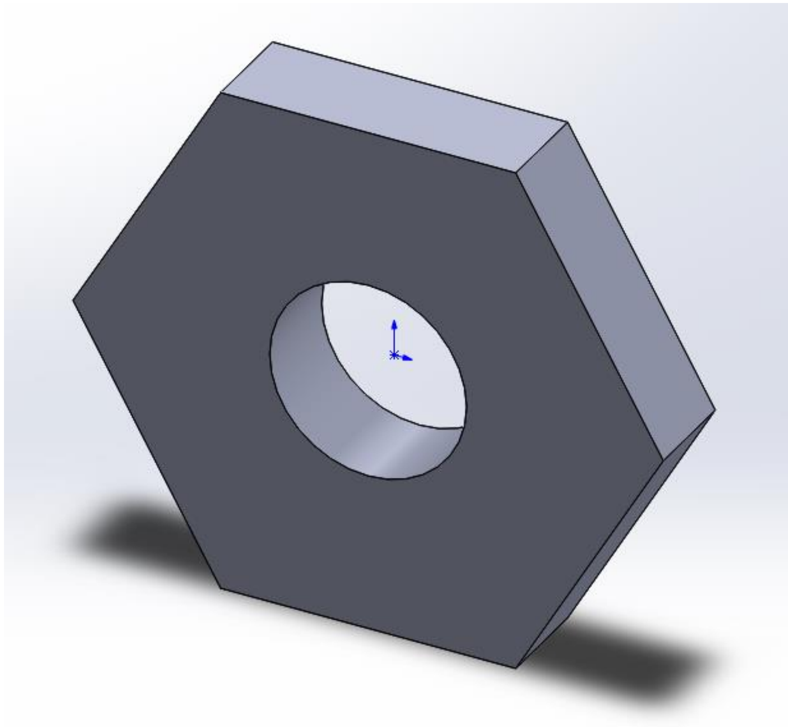
28. Rectangular Rubber Tubing



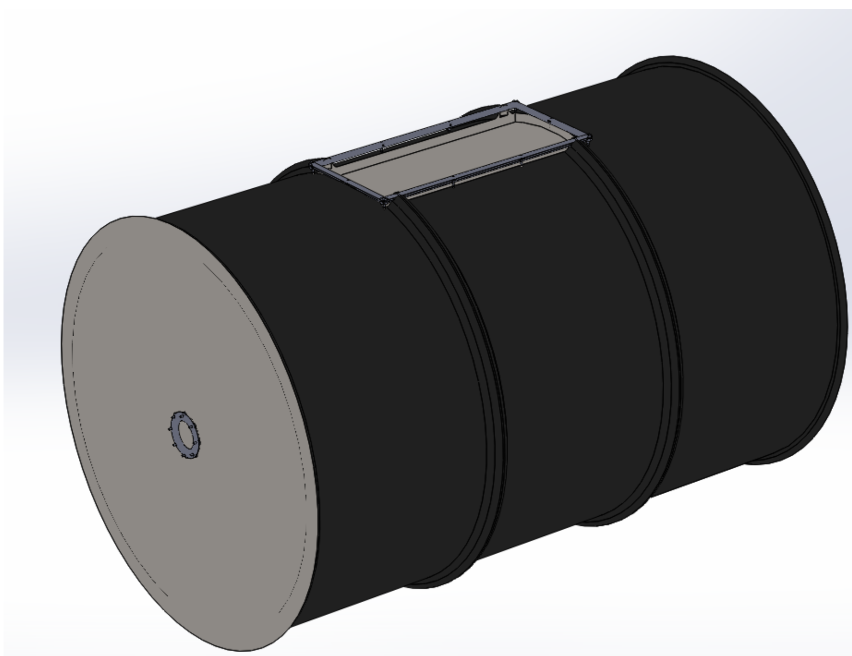
29. Small Flathead Screw



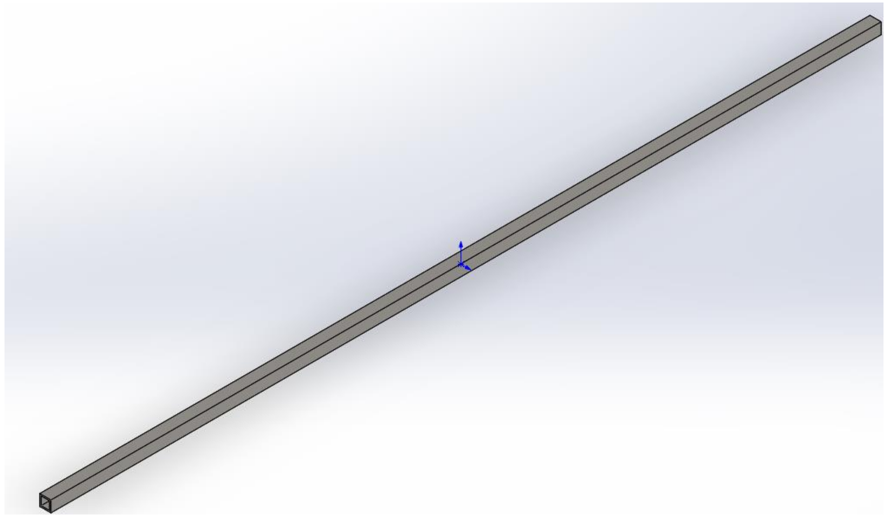
30. Small Nut



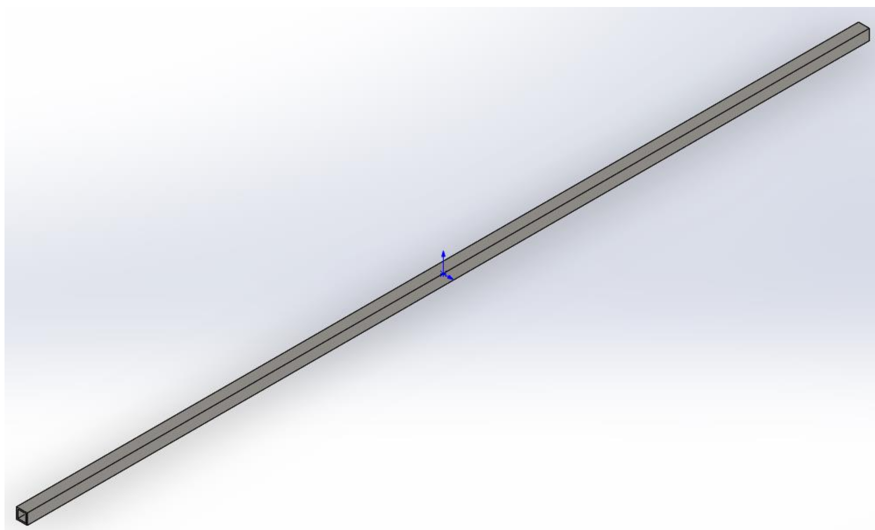
31. Drum with Rubber Coatings



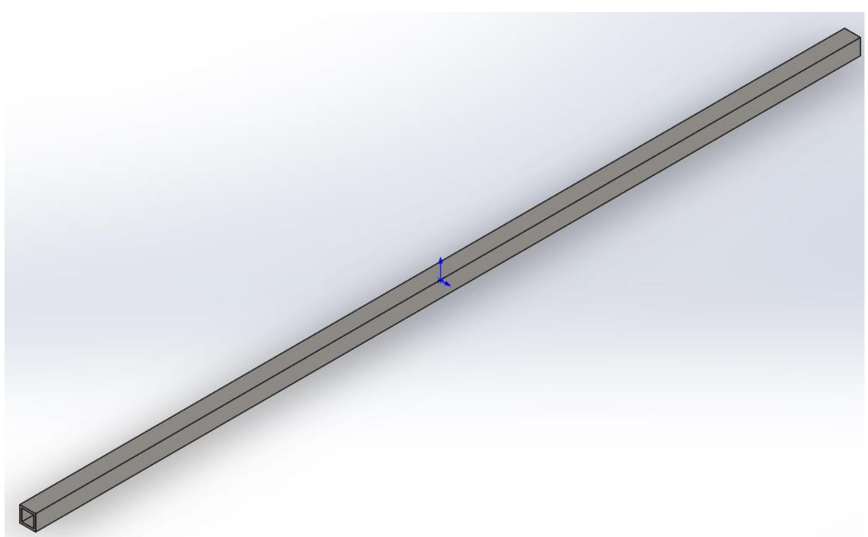
32. Outer Box Vertical 0.25” Metal Tubing



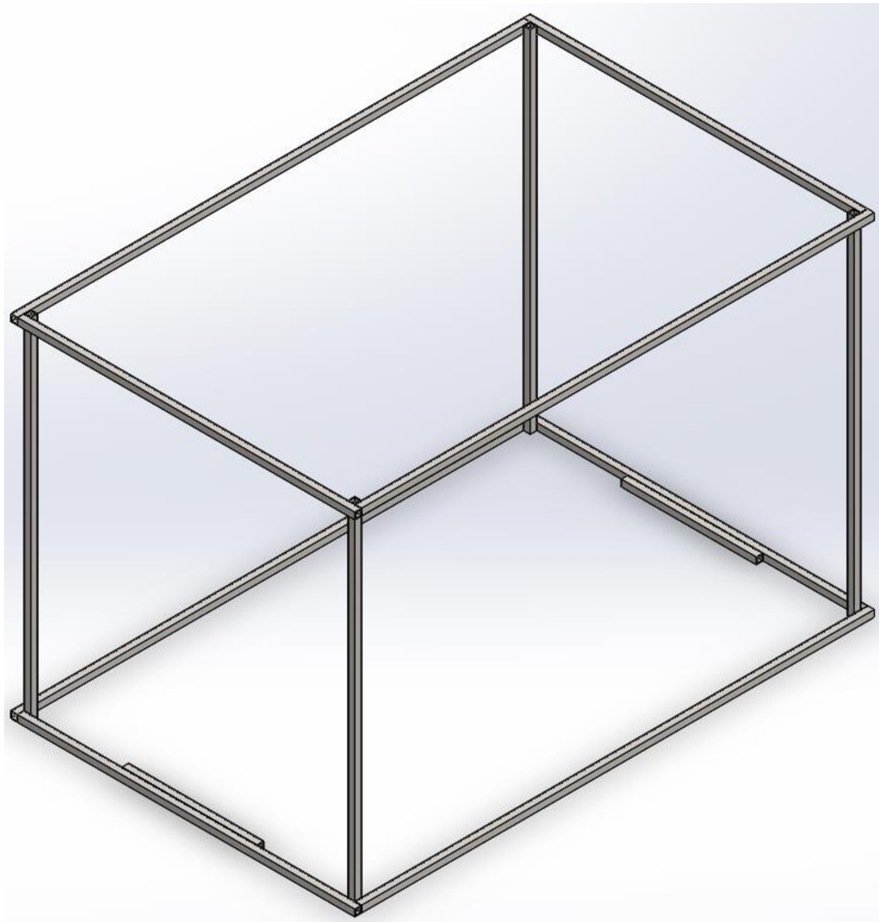
33. Outer Box Length 0.25” Metal Tubing



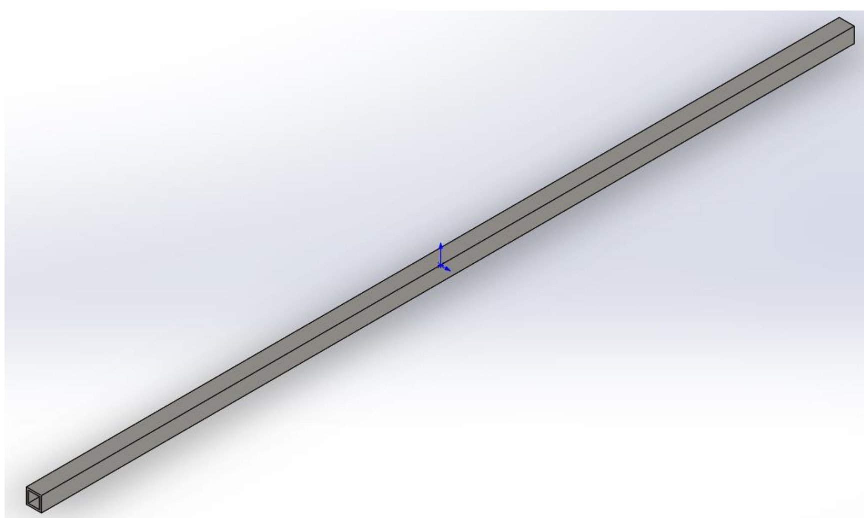
34. Outer Box Width 0.25” Metal Tubing



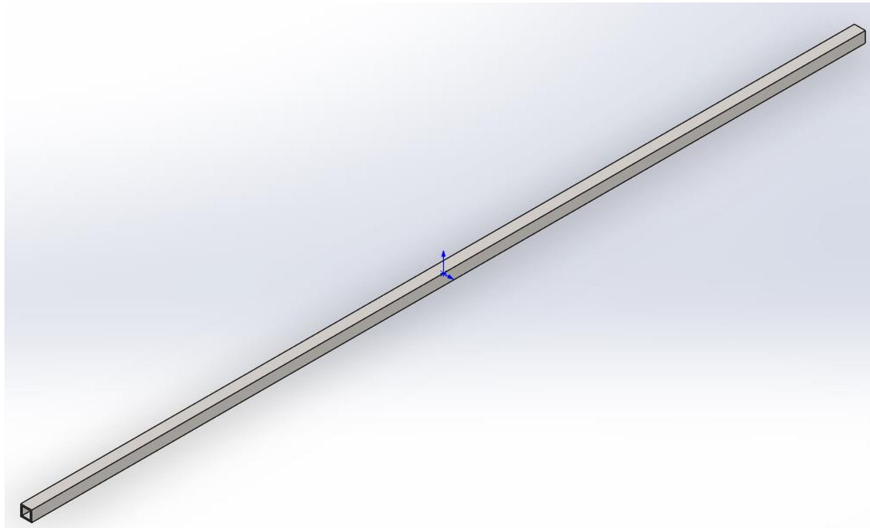
35. Outer Box



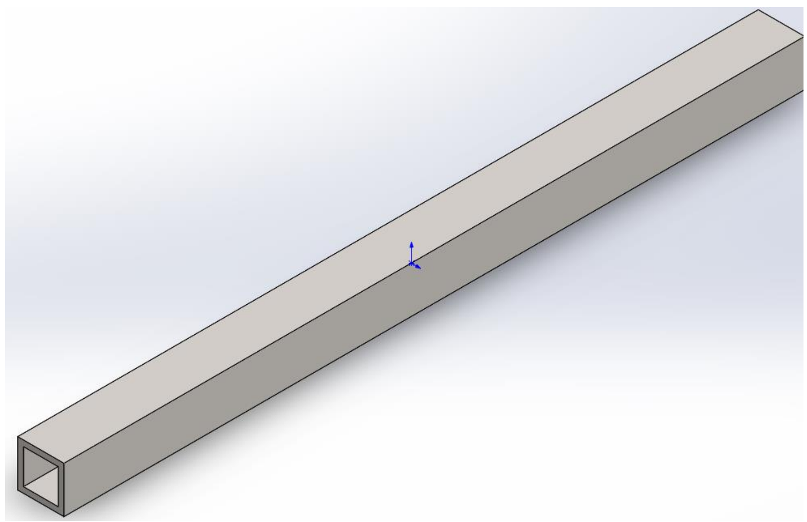
36. Inner Box Vertical 0.25” Metal Tubing



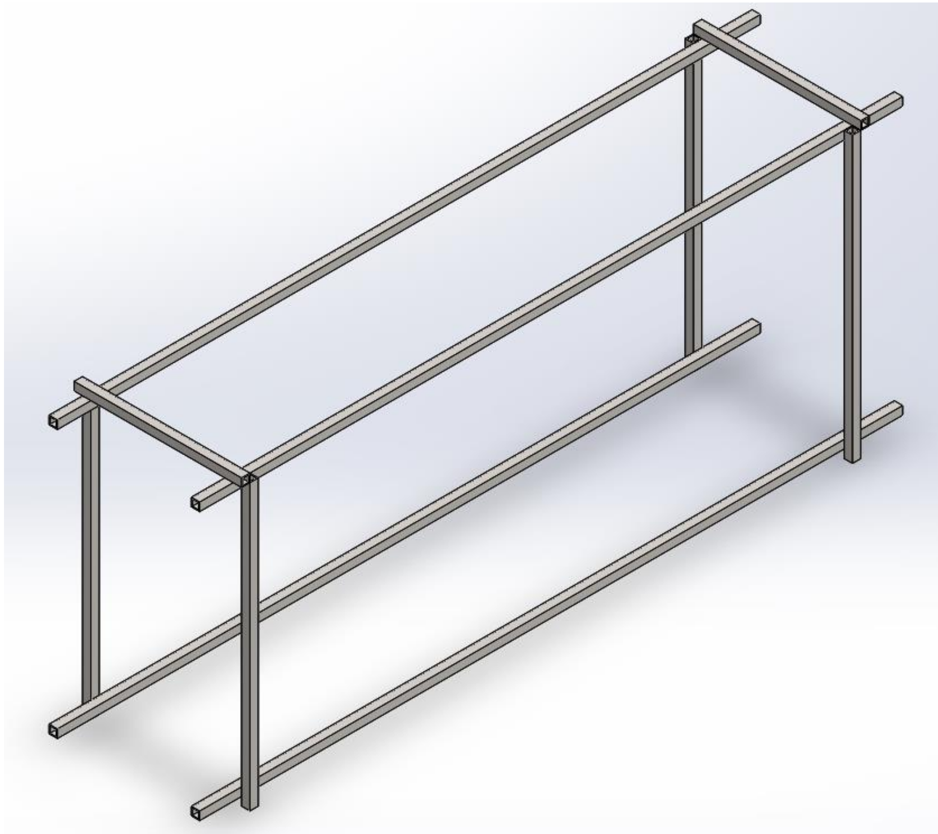
37. Inner Box Length 0.25” Metal Tubing



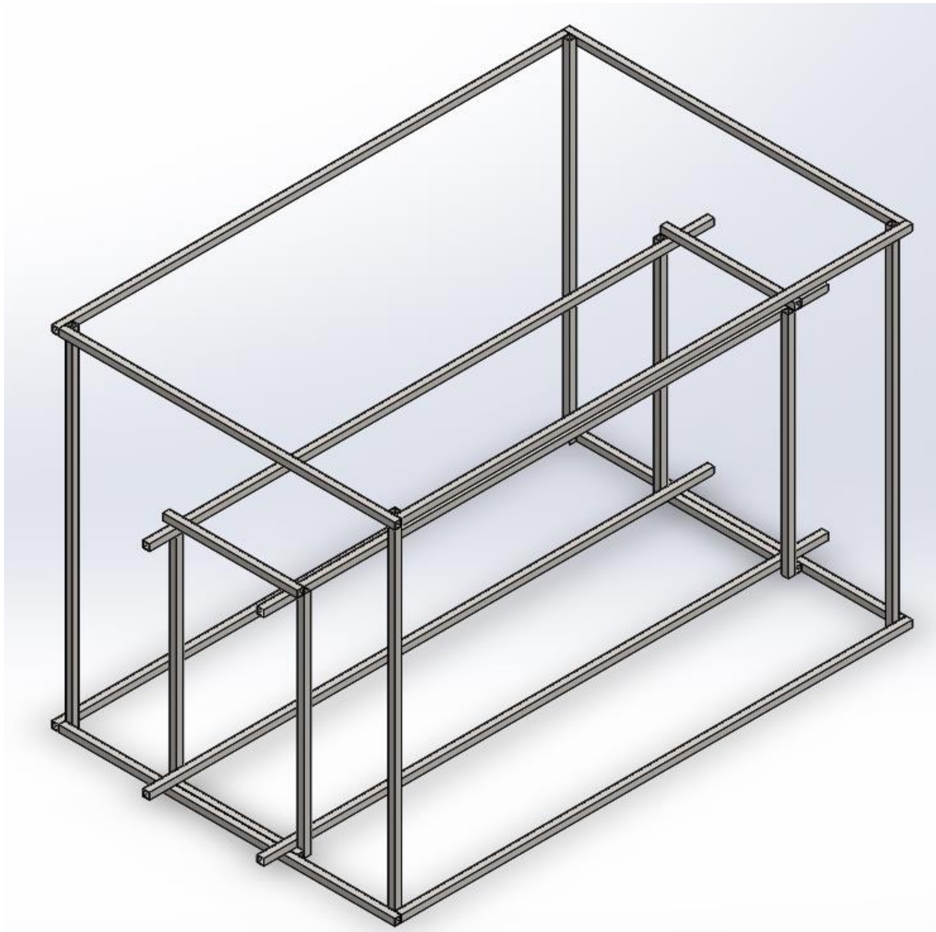
38. Inner Box Width 0.25” Metal Tubing



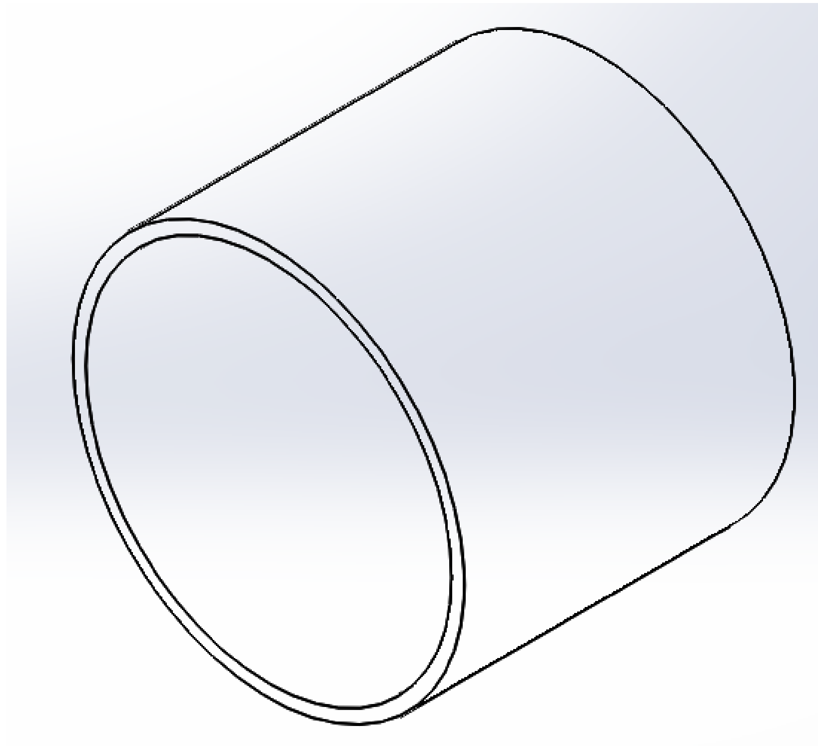
39. Inner Box



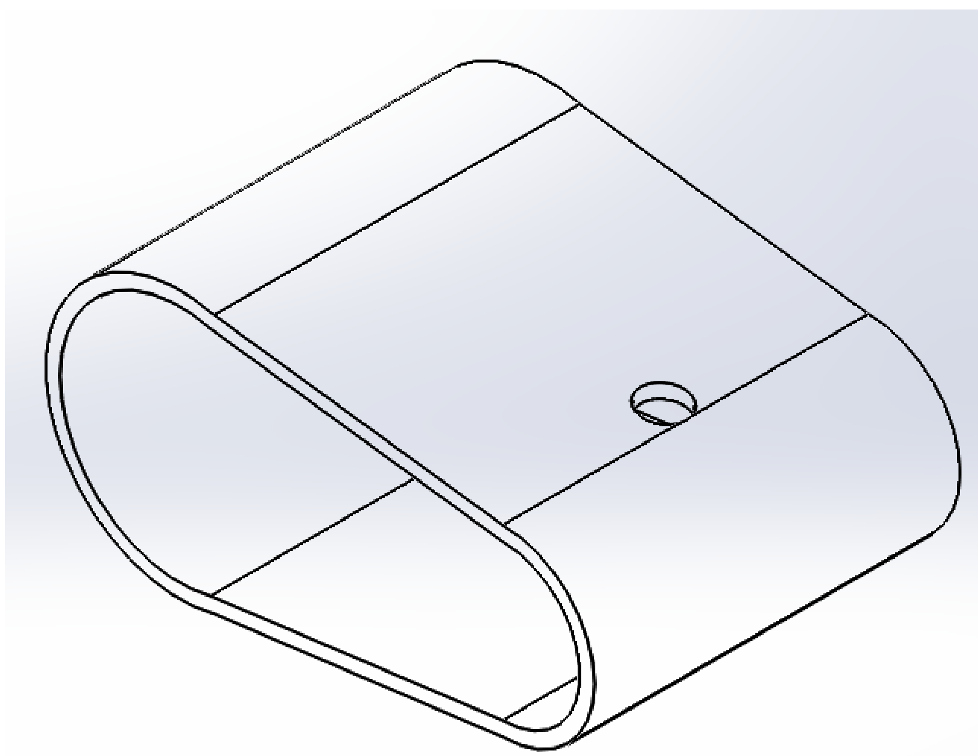
40. Box Assembly



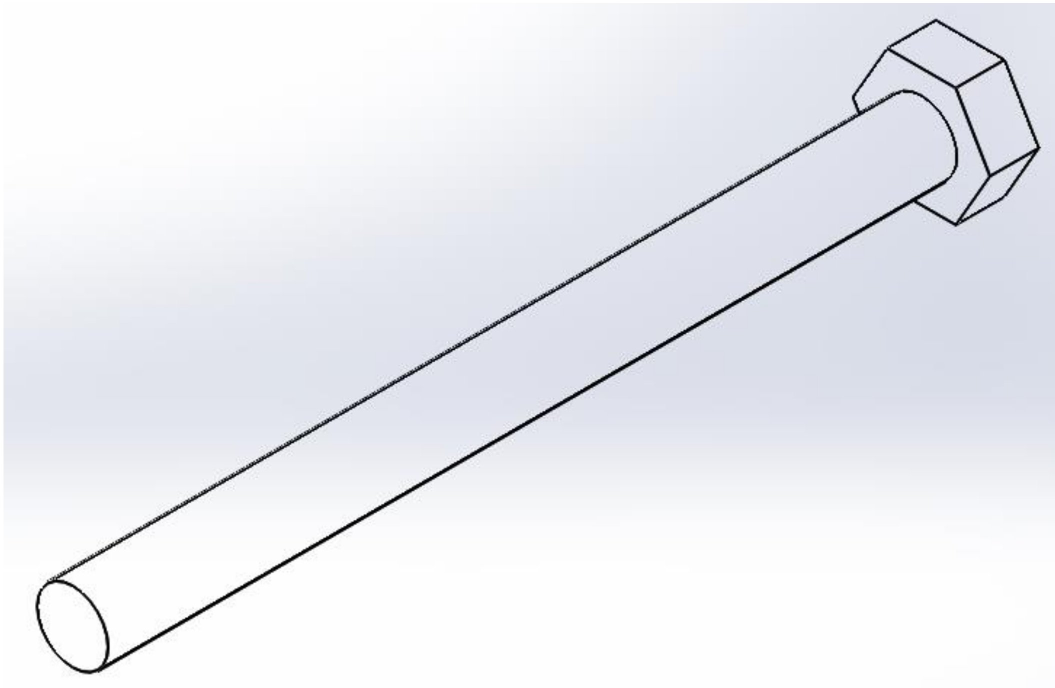
41. 2" PVC



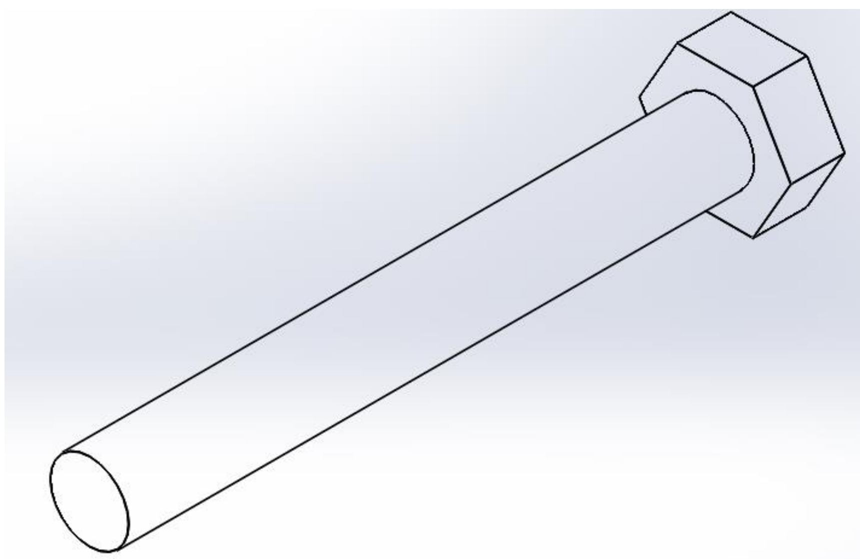
42. PVC Bearing



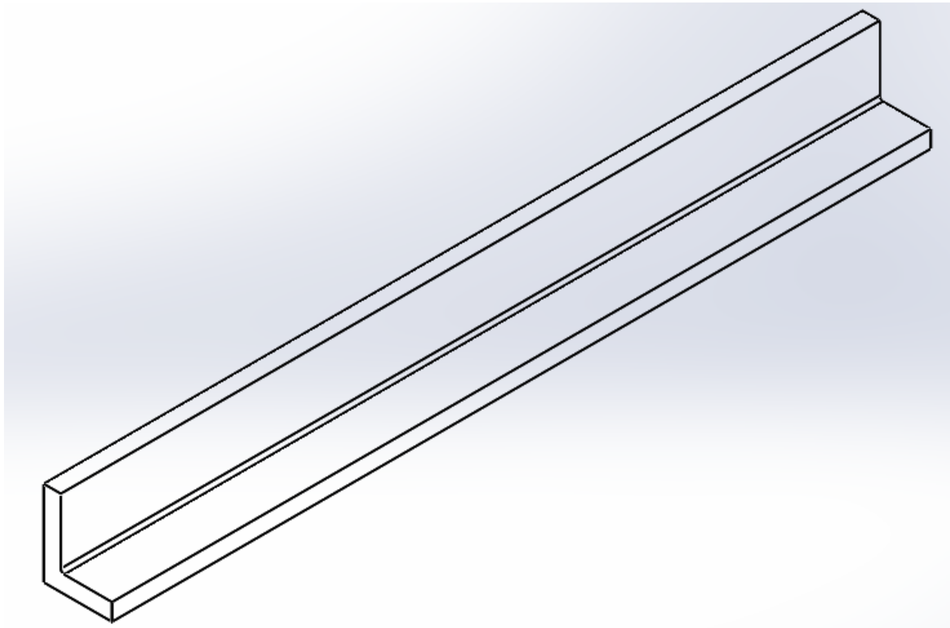
43. 3” Bolt



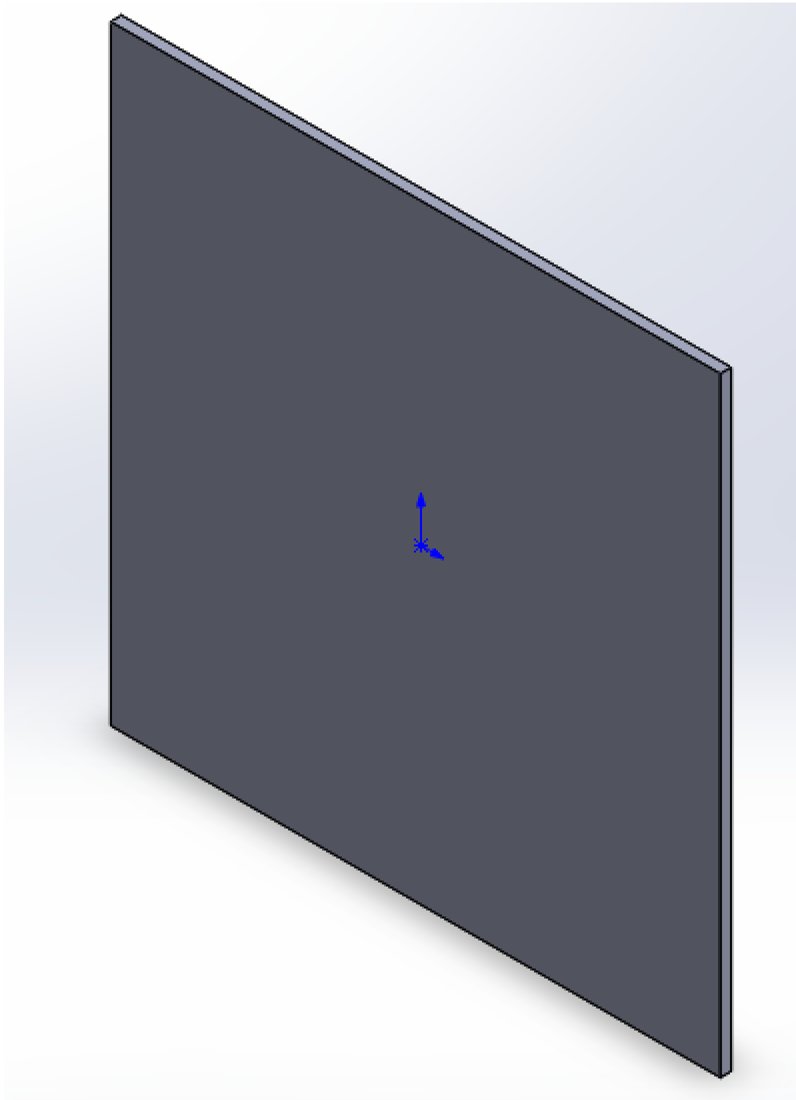
44. 2" Bolt



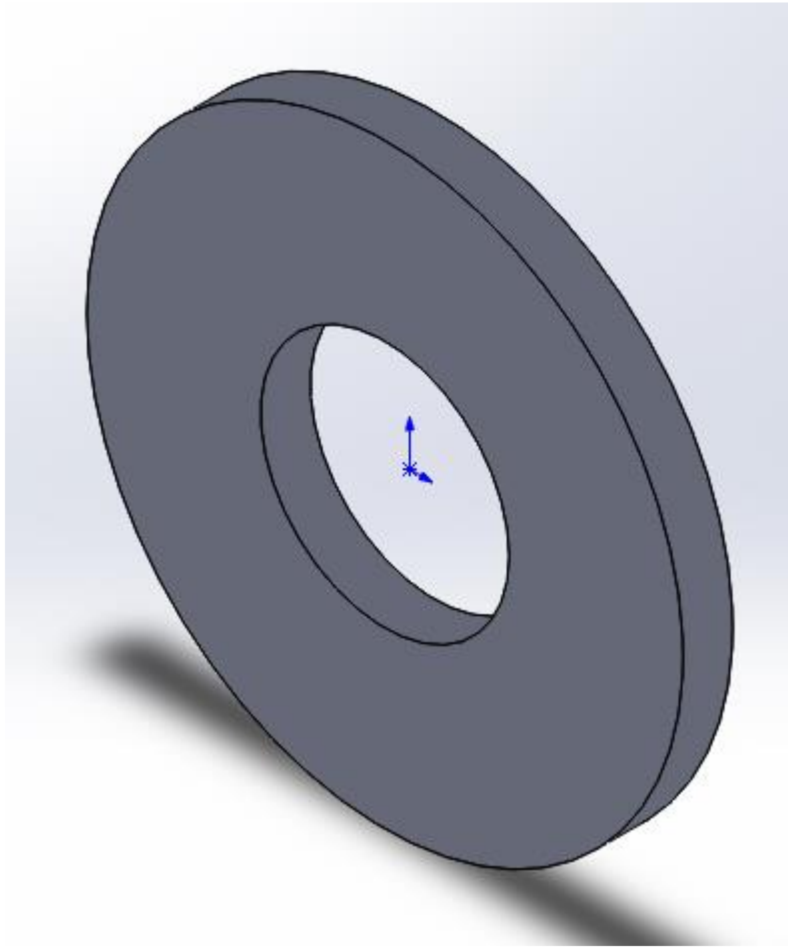
45. Angle Iron



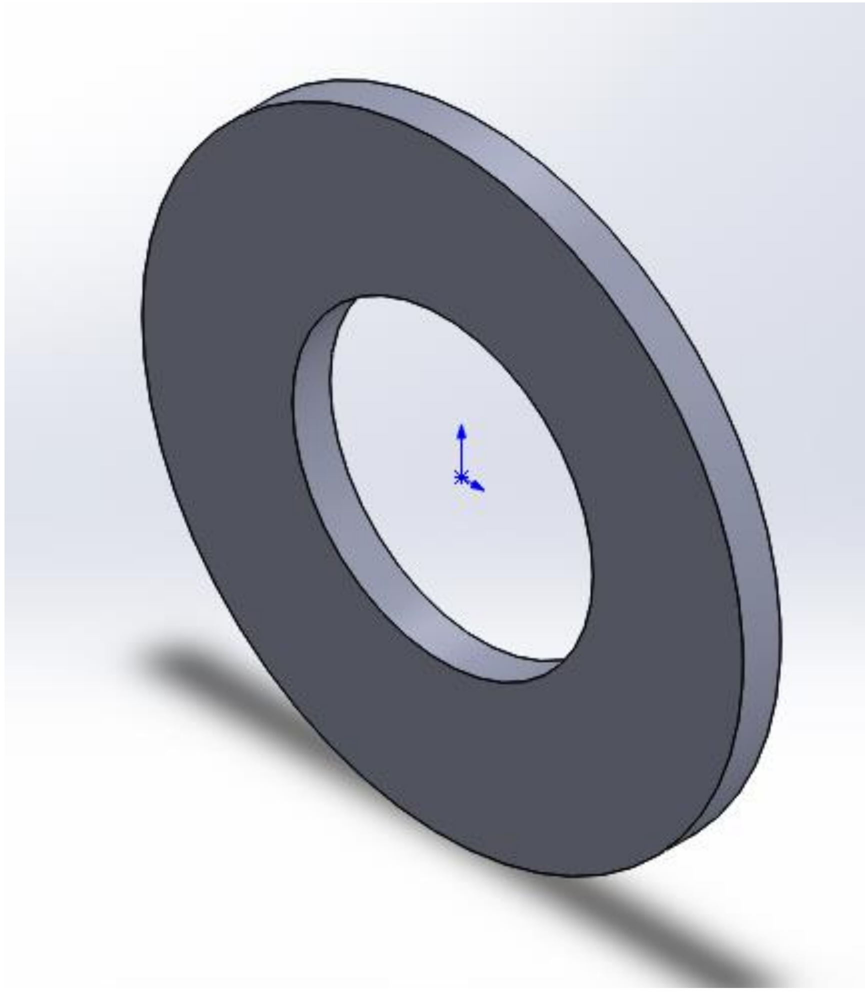
46. Rubber Seal

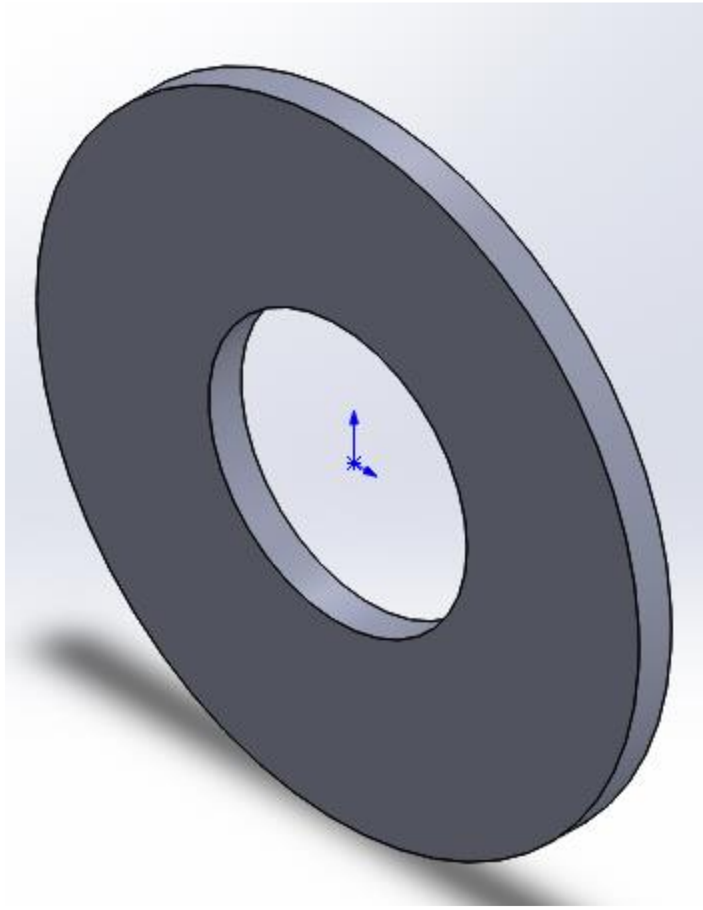


47. 0.75" Washer

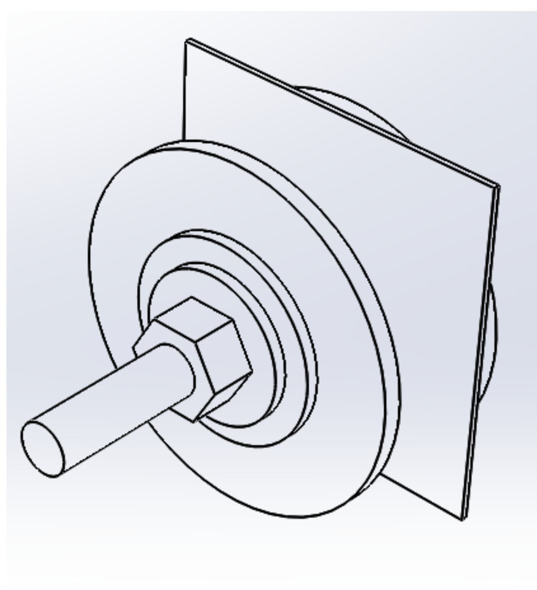


48. 1" Washer

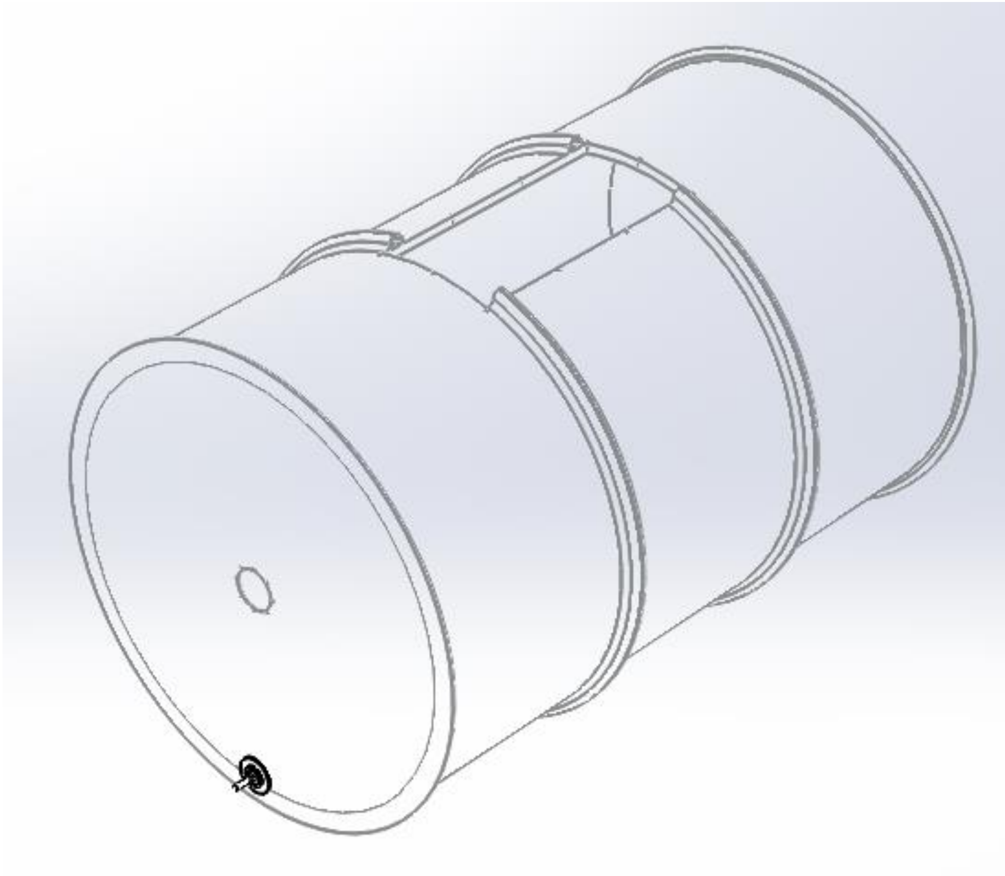

49. 1.75" Washer



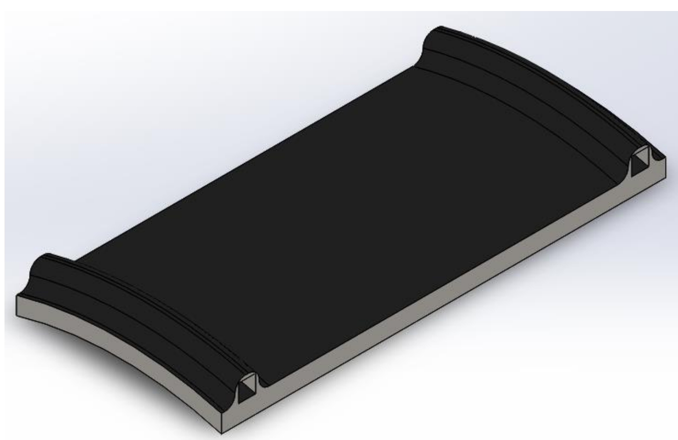
50. Plug



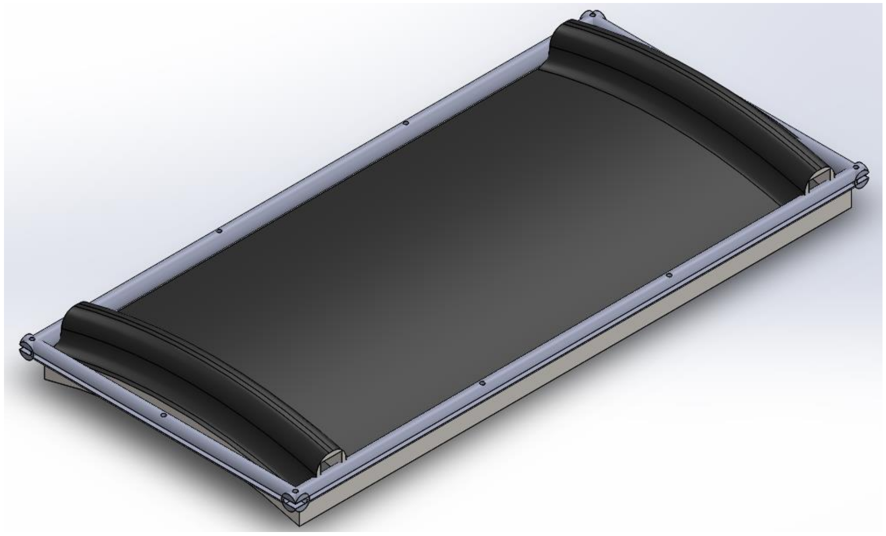
51. Plug in Drum



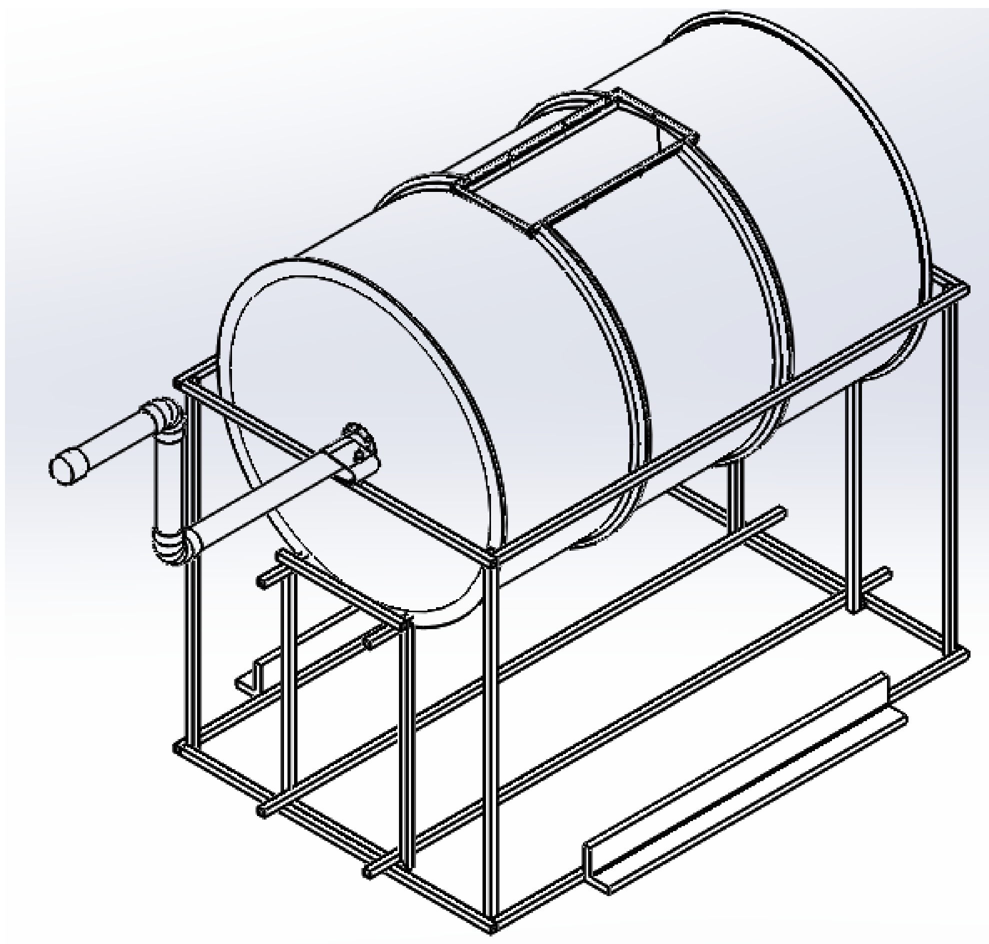
52. Lid



53. Lid with Rubber



54. Washing Machine Assembly



15 APPENDIX B – COMPUTER CODES

1. Finite Element Analysis for Three PVC Agitator Models

Table of Contents


```
clear
close
clc
```

PVC Agitator I

Estimating 2 inch Schedule 80 PVC

```
%https://www.engineersedge.com/fluid_flow/steel-pipe-schedule-80.htm
%Outside Diameter = 2.375 in
%Inside Diameter = 1.939 in
%Wall Thickness = 0.218 in
%http://www.usplastic.com/knowledgebase/article.aspx?contentkey=557
%Tensile Strength = 7450 psi
%https://www.aetnaplastics.com/site_media/media/attachments/
aetna_product_aetnaproduct/204/PVC%20Sch%2080%20Fittings
%20Dimensions.pdf
%Outisde Diameter of T-joint 2.875 in
%Length of T joint section 1.5 in
%Assume water in tank weighs 350 pounds, assume an average weight of
 300 lbs
%Assume max speed of crank at 4pi rad/s
OD=1.315; %in
ID=0.957; %in
T=0.179; %in
I=0.8680; %in^4
E=420000; %psi
w=100*pi; %lbf/in
% Element 1
L1=1.5; %in
k1=E*I/(L1^3); %lbf*in
K1=k1*[12 6*L1 -12 6*L1
      6*L1 4*L1^2 -6*L1 2*L1^2
      -12 -6*L1 12 -6*L1
      6*L1 2*L1^2 -6*L1 4*L1^2];
F1=[-3*w*L1/20; w*(L1^2)/30; -7*w*L1/20; -w*(L1^2)/20;]; %lbf
% Element 2
L2=9; %in
k2=E*I/(L2^3); %lbf*in
K2=k2*[12 6*L2 -12 6*L2
      6*L2 4*L2^2 -6*L2 2*L2^2
      -12 -6*L2 12 -6*L2
      6*L2 2*L2^2 -6*L2 4*L2^2];
F2=[-3*w*L2/20; w*(L2^2)/30; -7*w*L2/20; -w*(L2^2)/20; ]; %lbf
```

```
% Global Matricies
Kg=zeros(6,6);
Fg=zeros(6,1);
dof1=[1 2 3 4];
Kg(dof1,dof1)=Kg(dof1,dof1)+K1;
Fg(dof1)=Fg(dof1)+F1;
dof2=[3 4 5 6];
Kg(dof2,dof2)=Kg(dof2,dof2)+K2;
Fg(dof2)=Fg(dof2)+F2;
% Boundary Conditions
bc=1;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
bc=2;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
% Deflection
Ug=inv(Kg)*Fg
% Shear & Moment
S1=K1*Ug(dof1)
S2=K2*Ug(dof2)
```

```
Ug =

         0
         0
   -0.0338
   -0.0434
   -1.2254
   -0.1848


S1 =

   1.0e+04 *

    0.1579
    1.1734
   -0.1579
   -0.9366


S2 =

   1.0e+04 *

    0.0990
    1.0179
   -0.0990
```

```
-0.1272
```

PVC Agitator 2

```
OD=1.315; %in
ID=0.957; %in
T=0.179; %in
I=0.8680; %in^4
E=420000; %psi
w=100*pi; %lbf/in
% Element 1
L1=1.5; %in
k1=E*I/(L1^3); %lbf*in
K1=k1*[12 6*L1 -12 6*L1
      6*L1 4*L1^2 -6*L1 2*L1^2
      -12 -6*L1 12 -6*L1
      6*L1 2*L1^2 -6*L1 4*L1^2];
F1=[-3*w*L1/20; w*(L1^2)/30; -7*w*L1/20; -w*(L1^2)/20;]; %lbf
% Element 2
L2=5; %in
k2=E*I/(L2^3); %lbf*in
K2=k2*[12 6*L2 -12 6*L2
      6*L2 4*L2^2 -6*L2 2*L2^2
      -12 -6*L2 12 -6*L2
      6*L2 2*L2^2 -6*L2 4*L2^2];
F2=[-3*w*L2/20; w*(L2^2)/30; -7*w*L2/20; -w*(L2^2)/20; ]; %lbf
% Element 3
L3=4.375; %in
k3=E*I/(L3^3); %lbf*in
K3=k3*[12 6*L3 -12 6*L3
      6*L3 4*L3^2 -6*L3 2*L3^2
      -12 -6*L3 12 -6*L3
      6*L3 2*L3^2 -6*L3 4*L3^2];
F3=[-3*w*L3/20; w*(L3^2)/30; -7*w*L3/20; -w*(L3^2)/20; ]; %lbf
% Global Matricies
Kg=zeros(8,8);
Fg=zeros(8,1);
dof1=[1 2 3 4];
Kg(dof1,dof1)=Kg(dof1,dof1)+K1;
Fg(dof1)=Fg(dof1)+F1;
dof2=[3 4 5 6];
Kg(dof2,dof2)=Kg(dof2,dof2)+K2;
Fg(dof2)=Fg(dof2)+F2;
dof3=[5 6 7 8];
Kg(dof3,dof3)=Kg(dof3,dof3)+K3;
Fg(dof3)=Fg(dof3)+F3;
% Boundary Conditions
bc=1;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
```

```
bc=2;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
% Deflection
Ug=inv(Kg)*Fg
% Shear & Moment
S1=K1*Ug(dof1)
S2=K2*Ug(dof2)
S3=K3*Ug(dof3)


Ug =

         0
         0
   -0.0315
   -0.0403
   -0.4632
   -0.1183
   -1.0255
   -0.1345


S1 =

   1.0e+04 *

    0.1638
    1.1012
   -0.1638
   -0.8556


S2 =

   1.0e+03 *

    1.2370
    8.7826
   -1.2370
   -2.5975


S3 =

   1.0e+03 *

    0.4811
    2.4053
   -0.4811
   -0.3007
```

PVC Agitator 3

```
OD=1.315; %in
ID=0.957; %in
T=0.179; %in
I=0.8680; %in^4
E=420000; %psi
w=100*pi; %lbf/in
% Element 1
L1=1.5; %in
k1=E*I/(L1^3); %lbf*in
K1=k1*[12 6*L1 -12 6*L1
      6*L1 4*L1^2 -6*L1 2*L1^2
      -12 -6*L1 12 -6*L1
      6*L1 2*L1^2 -6*L1 4*L1^2];
F1=[-3*w*L1/20; w*(L1^2)/30; -7*w*L1/20; -w*(L1^2)/20;]; %lbf
% Element 2
L2=5; %in
k2=E*I/(L2^3); %lbf*in
K2=k2*[12 6*L2 -12 6*L2
      6*L2 4*L2^2 -6*L2 2*L2^2
      -12 -6*L2 12 -6*L2
      6*L2 2*L2^2 -6*L2 4*L2^2];
F2=[-3*w*L2/20; w*(L2^2)/30; -7*w*L2/20; -w*(L2^2)/20; ]; %lbf
% Global Matricies
Kg=zeros(6,6);
Fg=zeros(6,1);
dof1=[1 2 3 4];
Kg(dof1,dof1)=Kg(dof1,dof1)+K1;
Fg(dof1)=Fg(dof1)+F1;
dof2=[3 4 5 6];
Kg(dof2,dof2)=Kg(dof2,dof2)+K2;
Fg(dof2)=Fg(dof2)+F2;
% Boundary Conditions
bc=1;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
bc=2;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
bc=5;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
Fg(bc)=0;
bc=6;
bc_val=0;
Kg(bc,:)=0;
Kg(bc,bc)=1;
```

```
Fg(bc)=0;
% Deflection
Ug=inv(Kg)*Fg
% Shear & Moment
S1=K1*Ug(dof1)
S2=K2*Ug(dof2)


Ug =

   1.0e-03 *

         0
         0
   -0.3400
   -0.0588
         0
         0


S1 =

  383.5117
  301.9213
 -383.5117
  273.3462


S2 =

  -17.0414
  -46.8897
   17.0414
  -38.3172
```

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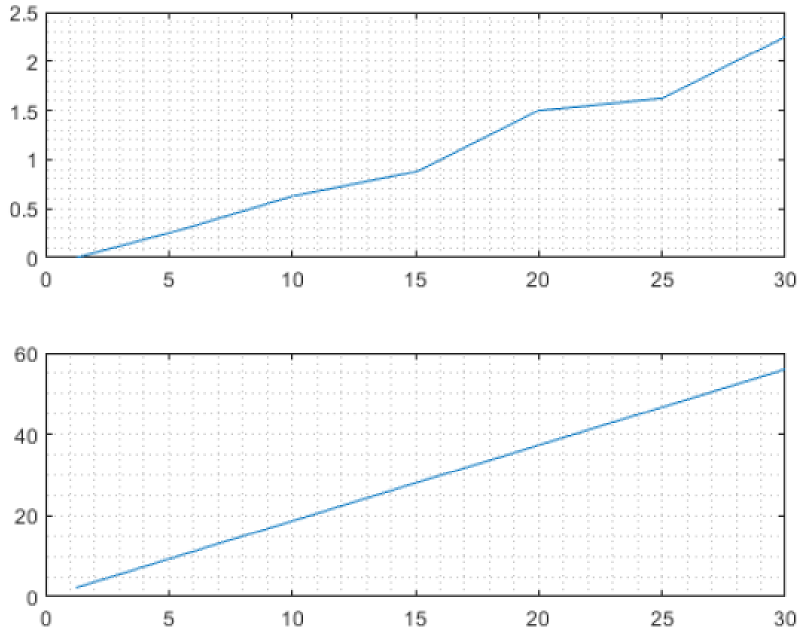
This MATLAB Code was created to perform a Finite Element Analysis of three possible agitators. This code was able to show the deflection and stress on the fins of the agitator, based on the alignment and support of the fins. This code differs slightly from the actual constructed agitator, because the code assumes two-inch, schedule 80 PVC. For the agitators that were constructed and tested, one-inch, schedule 40 was used. The first iteration of the agitator was based on the “PVC Agitator 2” in this file.

2. Bending Test

Bending Experiment Data

```
close all, clear all, clc

F = [1.25; 5.0; 10.0; 15.0; 20.0; 25.0; 30.0]; % lbs, applied weight
df = [0; 0.25; 0.625; 0.875; 1.5; 1.625; 2.25]; % in, deflection
OD = 1.32; % in, outside diameter of pipe
ID = 1.03; % in, inside diameter of pipe
t = 0.145; % in, wall thickness of pipe
CSA = .25*pi*(OD^2) - .25*pi*(ID^2); % in^2, cross-sectional area of
 pipe
sigma = F./CSA; % psi, normal stress in pipe

a = 1;
for u = 1:(length(F)-1);
    slope(a) = (F(u+1)-F(u)) / (df(u+1)-df(u));
    a = a+1;
end
avgslope = (sum(slope)) / (length(slope));
L = 52; % in, length of pipe beam
totmass = (1 + 9.3/16)/32.2; % slugs, total mass of pipe
totlength = 60.25; % in, total length of pipe
M = (L/totlength)*totmass; % slugs, mass of pipe beam
I = .5*M*((OD/2)^2+(ID/2)^2);
E = avgslope * ((L^3)/(48*I))

subplot(2,1,1)
plot(F,df)
grid minor
subplot(2,1,2)
plot(F,sigma)
grid minor


E =

   3.4298e+06
```



This MATLAB code shows the results of the bending test preformed on one-inch PVC tubing. It can be seen that as the load increased, so did the deflection of the PVC. From this data, the modulus of elasticity of the PVC was able to be estimated.

3. Concrete Teeth Calculations

Table of Contents

Power Source Calculations

```
close all
clear all
close all
```

PVC Calculations

This is the calulation for the deflection and shear of the pvc roller in the middle of the power source. This acts as the pivot point for the beam

```
l = 24; % length of the overall beam in inches
F = 130*12; % Force at the end of the beam in inch pounds
M = F*l; % reaction force
E = 420*10^3; % Youngs modulus of PVC in psi
do = 1.25; % outer diameter of 1 inch PVC in inches
di = 1; % inner diameter
I = (pi/64)*((do^4)-(di^4)); % moment of inertia of a hollow circular
 tube
c = do/2; % half thickness of tube
L = 6; % length of roller from "X to X" in inches
L = L/2; % length of roller from mid to X in inches
deflection = (M*L^3)/(48*E*I); % in inches
stress = M*L*c/I;

fprintf('The maximum deflection of the PVC roller if someone steps
 with %0.2f foot pounds is %0.2f inches\n\n',F/12,deflection)
fprintf('The maximum stress of the PVC roller in this case is %0.2f
 psi\n',stress)
```

```
The maximum deflection of the PVC roller if someone steps with 130.00
 foot pounds is 0.71 inches

The maximum stress of the PVC roller in this case is 992157.94 psi
```

Tooth Shear

This is the calculation for the shear on one tooth of the concrete ratchet used in the transmission

```
thickness = 1.5; % thickness of tooth in inches
fc = 3000; % psi of quickcrete 24h
% d is the width of each tooth from base to tip
v = @(d) 2*((fc)^0.5)*thickness*d; % this is the equation to be
 integrated
```

1

```
endcond = 0; % this is the condition at the tip
initialcond = 0.72; % this is the condition at the base (thickness)
V = integral(v,endcond,initialcond); % Average shear stress in force
 pounds
fprintf('\nIf the ratchet is %0.3f inches thick, the average shear
 stress in each tooth is %0.3f foot pounds\n',initialcond,V)
%
% We assumed the hinge would stop touching the tooth 2/3 of the way
 down
% the tooth face. We also assumed that the force being applied to the
 tooth
% is 4.88 foot pounds. This loop ensures that the 2/3 point can handle
 the
% force applied, before a factor of safety.
%
v = 0; % initial shear stress for loop
d = (1/3)*0.72; % This is the assumed point of no contact
thickness = 0; % initial thickness of tooth for loop
%
while v < 4.88
    v = 2*((fc)^0.5)*thickness*d;
    thickness = thickness+0.01;
end
%
fprintf('\nFor the expected shear stress of 4.88 food pounds at a
 location of %0.2f inches from the tooth tip,\nthe ratchet thickness
 needs to be %0.3f inches\n',d,thickness)
```

```
If the ratchet is 0.720 inches thick, the average shear stress in each
 tooth is 42.591 foot pounds

For the expected shear stress of 4.88 food pounds at a location of
 0.24 inches from the tooth tip,
the ratchet thickness needs to be 0.200 inches
```

This code calculates the stress applied on individual teeth of a molded gear. It shows that the gear would have been strong enough to power the washing machine. This was a great factor into designing the type of ratchet to be molded.

4. Bending and Deflection in the PVC/Threaded Rod Ratchet

Table of Contents


```
clear
close
clc
```

Bolt Bending

```
format short g
% 0.25 inch bolt
% using 80lbf
% Assume cantilever beam
% SAE Grade 1 Bolt yield=36000 psi Sut=60000psi Proof=33000psi
% Assume PVC diameter is 1 inch
% Assume bolt is 3 inches long...so beam is 1 inch on each end
% Door hinge hits bolt at point l

disp('One Bolt')
Sut=60000; %psi Ultimate Tensile Strength of bolt
Sy=36000; %psi Yield Strength of bolt
Sp=33000; %psi Proof Strength of bolt
E=30*10^6; %psi YOungs Modulus
d=0.25;%in Bolt Diameter
r=d/2; %in Bolt radius
m=8.32*10^-4; %lb bolt mass
l=1;%in Exposed bolt length
Iy=(1/12)*(m*(3*(r^2)+(l^2))); %in^4 Moment of Inertia
F=80;%lbf Force on Bolt
A=pi*(d^2)/4;%in^2 Bolt Cross Sectional Area
Deflection=(F*l^3)/(3*E*Iy)
disp('inches')
Stress1=F/A % Stress on Bolt
disp('psi')
FOS=Sp/Stress1 % Facor of Safety

% If we use two bolts equidistant from center...
disp('Two Bolts')
F=40; %lbf Force distributed on two bolts
Deflection=(F*l^3)/(3*E*Iy)
disp('inches')
```

```
Stress2=F/A % Stress on Bolt
disp('psi')
FOS=Sp/Stress2 % Facor of Safety
```

1

```
One Bolt

Deflection =

     0.012246

inches

Stress1 =

       1629.7

psi

FOS =

       20.249

Two Bolts

Deflection =

    0.0061232

inches

Stress2 =

       814.87
```

```
psi

FOS =

       40.497
```

Bolt Life

Sut<200kpsi...so Se'=.5Sut machined or cold drawn in bending

```
disp('One Bolt')
Sut=60; %kpsi Ultimate Tensile Strength
Sy=36; %kpsi Yield Strength
SE=Sut/2; %kpsi Endurance Limit
a=2.7;
b=-2.65;
ka=a*(Sut/(10^3))^b; %Surface Factor
kb=0.879*(d^-.107); %Size Factor
Se=ka*kb*SE; %kpsi Endurance Limit
Sm=Stress1/(2*10^3); %kpsi Midrange stress
Sa=Sm; %kpsi Amplitude stress
```



```
% Fatigue Factors of Safety
disp('Fatigue Factors of Safety')
disp('Goodman')
nf=1/((Sa/Se)+(Sm/Sut)) %Goodman Factor of Safety
disp('Gerber')
nf=.5*((Sut/Sm)^2)*(Sa/Se)*(-1+sqrt(1+((2*Sm*Se)/(Sut*Sa)))) %Gerber
 Factor of Safety
disp('Soderberg')
nf=1/((Sa/Se)+(Sm/Sy)) %Goodman Factor of Safety
disp('ASME Elliptic')
nf=sqrt(1/(((Sa/Se)^2)+((Sm/Sy)^2))) %ASME Elliptic Factor of Safety
```

```
% Fatigue Life
f=0.9; %Fatigue Strength Fraction
a=((f*Sut)^2)/Se;
b=-(1/3)*log10(f*Sut/Se);
disp('Finite Life')
Sf=f*Sut; %kpsi Fatigue Strength for Finite Life
N=(Sf/a)^1/b
disp('cycles')
disp('Infinite Life')
Sf=Se; %kpsi Fatigue Strength for Infinite Life
N=(Sf/a)^1/b
disp('cycles')
```

```
One Bolt
Fatigue Factors of Safety
Goodman

nf =

         73.6

Gerber

nf =

       1.0518

Soderberg

nf =

       44.168

ASME Elliptic

nf =

       44.179

Finite Life

N =
```

```
        2318.4

cycles
Infinite Life

N =

   6.1318e+06

cycles
```

Shearing PVC

Assume PVC is small flat square Yield Stress for PVC 8000 psi Can assume force on bolt (80lbf)is same on PVC

```
Sy=8000; %psi Yield Strength of PVC
F=80; %lbf force on PVC
t=0.133; %in PVC thickness
c=pi*r; %in half circumfrence of bolt
A=t*c; %in^2 Bolt active area
E=410000; %psi youngs modulus PVC
Shear=F/A % Stress on PVC
disp('psi')
FOS=Sy/Shear % Facor of Safety
```

```
Shear =

        1531.7

psi

FOS =

        5.2229
```

This MATLAB code shows the projected deflection, stress and life of the threaded rods and the shear in the PVC. These calculations proved that the threaded rod ratchet would successfully hold up against the projected power needed to power the washing machine. The factors of safety in all cases showed that it was extremely unlikely that the ratchet would fail.

5. Stepper Calculations

Table of Contents

Powering Calculations

```
clear all
close all
clc
```

Shaft height - 20 5/8" vertical

```
% LT = 32; % in, total length of stepper board
% Y = 24; % in, peak height of stepper board tip
% Th1 = asind(Y / LT); % degrees, angle of stepper board in "down"
 position
% PH = 8; % in, height of pivot bar
% d1 = PH / sind(Th1); % in, total length of operator side of board
% d2 = LT - d1; % in, total length of ratchet side of board
% Th2 = asind(PH / d2); % degrees, angle of stepper board in "up"
 position
% ThT = Th1 + Th2; % degrees, total stroke angle
% T2 = 11.71; % ft-lbs, applied ratchet torque
% RR = [3.5] / 12; % ft, radius of the ratchet
% F2 = T2 / RR; % lbs, force applied to ratchet
% F1 = (d2 / d1) * F2; % lbs, force applied by operator
% T1 = (F1 * d1) / 12; % ft-lbs, torque applied by operator
```

3/14 Re-Design

```
Y = 20; % in, peak height of stepper board tip
alt1 = 3.625; % in, bottom point of operator side of board
alt2 = 9.25; % in, top point of operator side of board
T2 = 20; % ft-lbs, applied ratchet torque
LT = 42; % in, total length of stepper board
RR = [2.5] / 12; % ft, radius of the ratchet
F2 = T2 / RR; % lbs, force applied to ratchet
d1 = 30; % in, total length of operator side of board
d2 = 12; % in, total length of ratchet side of board
F1 = (d2 / d1) * F2; % lbs, force applied by operator
T1 = (F1 * d1) / 12; % ft-lbs, torque applied by operator
Th2 = asind(Y/LT); % degrees, angle of stepper board in "up" position
PH = d1*sind(Th2); % in, height of pivot bar
Th1 = asind((PH-alt2)/d1); % degrees, angle of stepper board in "down"
 position
ThT = Th1 + Th2; % degrees, total stroke angle
```

These calculations were used to assist in the calculation of the stepper lengths with regards to the hinge height. This calculation was based on the average comfortable stepping height of all team members. The stepper was built using these calculations.

16 APPENDIX C – TEAM MEMBER QUALIFICATIONS

WESLEY E. EIDT

203 Russ Engineering Center, Wright State University eidt.2@wright.edu (419) 689-1285

EDUCATION

Bachelor of Science in Mechanical Engineering Wright State University, Dayton, Ohio • GPA 3.96/4.0 **General Honors Designation** **Minor in Mathematics**	**May 2019**

WORK EXPERIENCE

Mechanical Engineering Intern **Mansfield Engineered Components, Mansfield, OH** • Created and updated CAD models, performed and recorded results of laboratory tests.	**May 2018-Aug 2018**
Calculus II Lab Assistant **Wright State University, Dayton, OH** • Graded papers, assisted labs, and provided feedback to students.	**Jan 2017-May 2017**

College Algebra Learning Assistant **Wright State University, Dayton, OH** • Provided in-class aid to students, proctored exams.	**Aug 2016-Dec 2016**
Customer Assistance Associate **Lowe's, Ontario, OH** • Helped patrons with all aspects of their home improvement shopping experience. **Self-Operating Sweet Corn Producer** **Shelby, OH** • Planted, tended, harvested, and sold sweet corn as an independent operation	**May 2016-Aug 2016** **2009-2013**

SKILLS

▪ MATLAB ▪ Working Model ▪ Bobcat	▪ Microsoft Office ▪ Multisim	▪ SolidWorks ▪ Labview

RELEVANT COURSEWORK

▪ Engineering Design and Solid Modeling ▪ Engineering Programing with MATLAB ▪ Mechanics of Materials ▪ System Dynamics	▪ Calculus I, II, & III ▪ Statics ▪ Thermodynamics I & II ▪ Differential Equations ▪ Fluid Dynamics ▪ Heat Transfer ▪ Engineering Statistics	▪ Physics I & II ▪ Dynamics ▪ Structures and Properties of Materials ▪ Experimental Measures and Instrumentation ▪ Mechanical Vibrations

- Mechanical Design I & II - Chemistry	- Finite Element Analysis	- Linear Algebra

TRAINING AND CERTIFICATES

Tau Beta Pi	**April 2018**
Valedictorian	**May 2015**
National Merit Commended Scholar	**October 2013**

JACOB M. ERWIN

203 Russ Engineering Center, Wright State University erwin.34@wright.edu (937)-467-9443

EDUCATION

Bachelor of Science in Mechanical Engineering Wright State University, Dayton, Ohio • GPA 3.23/4.0 **Minor in Mathematics**	**May 2019**

WORK EXPERIENCE

Engineering Intern **Air Transport International, Wilmington, OH** • Complete part effectivity requests • Assist the engineering department with various tasks	**May 2018-Current**
General Hand/Team member **Eldora Speedway, New Weston, OH** • Controlled situations before conflicts arose with fans and solved problems • Worked in small teams to ensure operations ran as intended	**June 2014-October 2018**
Solidworks (CAD) Teaching Assistant **Wright State University, Dayton, OH** • Clarified basic Solidworks skills to those new to it and ensured	**January 2016-April 2016**

understanding within that department of engineering for each student • Advised students during office hours to provide one on one assistance	

SKILLS

▪ MATLAB ▪ Mathematica ▪ Working Model	▪ Microsoft Office ▪ Multisim ▪ Bobcat	▪ SolidWorks ▪ Labview

RELEVANT COURSEWORK

▪ Engineering Design and Solid Modeling ▪ Engineering Programing with MATLAB ▪ Mechanics of Materials ▪ System Dynamics ▪ Mechanical Design I & II	▪ Calculus I, II, & III ▪ Statics ▪ Thermodynamics ▪ Differential Equations ▪ Fluid Dynamics ▪ Heat Transfer ▪ Linear Algebra ▪ Finite Element Analysis	▪ Physics I & II ▪ Dynamics ▪ Structures and Properties of Materials ▪ Experimental Measures and Instrumentation ▪ Mechanical Vibrations ▪ Corrosion

Bradley J. Franks

203 Russ Engineering Center, Wright State University franks.30@wright.edu (304) 939-0176

EDUCATION

Bachelor of Science in Mechanical Engineering Wright State University, Dayton, Ohio • GPA 3.798/4.0	**May 2019**

WORK EXPERIENCE

Heat Transfer Grader **Wright State University, Dayton, OH** • Graded papers and provided feedback to students.	**2019**
Calculus II Lab Assistant **Wright State University, Dayton, OH** • Graded papers and provided feedback to students.	**2018-Present**
System Dynamics Grader **Wright State University, Dayton, OH** • Graded papers and provided feedback to students.	**2018-Present**
Mechanical Design I Grader **Wright State University, Dayton, OH**	**2018**

• Graded papers, assisted labs, and provided feedback to students. **Student Trainee** **United States Army Corps of Engineers, Huntington, WV** • Worked on engineering drawings using Microstation.	**2016-Present**
Tour and Zoo Guide **Heritage Farm Museum and Village, Huntington, WV** • Provided education assistance to tour groups.	**2013-2016**

SKILLS

▪ MATLAB ▪ Microstation ▪ Working Model	▪ Microsoft Office ▪ Multisim ▪ Bobcat	▪ SolidWorks ▪ Labview

RELEVANT COURSEWORK

▪ Engineering Design and Solid Modeling ▪ Engineering Programing with MATLAB ▪ Mechanics of Materials ▪ System Dynamics ▪ Mechanical Design I & II	▪ Calculus I, II, & III ▪ Statics ▪ Thermodynamics ▪ Differential Equations ▪ Fluid Dynamics ▪ Heat Transfer ▪ Wind Power ▪ Finite Element Analysis	▪ Physics I & II ▪ Dynamics ▪ Structures and Properties of Materials ▪ Experimental Measures and Instrumentation ▪ Mechanical Vibrations ▪ Corrosion

TRAINING AND CERTIFICATES

Tau Beta Pi	**November 2018**
Peer Tutor	**2016**
Valedictorian	**May 2015**
Eagle Scout	**June 2011**

RYAN X. KINKADE

203 Russ Engineering Center, Wright State University kinkade.4@wright.edu (937) 825-7341

EDUCATION

Bachelor of Science in Mechanical Engineering Wright State University, Dayton, Ohio • GPA 3.48/4.0	**May 2019**

WORK EXPERIENCE

Research Assistant **Air Force Institute of Technology, Dayton, OH** • Perform research on various electrical, physical, and mechanical subjects • Work directly with sponsors on their projects	**June 2017-Present**
Custodian **Beavercreek Church of the Nazarene, Beavercreek, OH** • Responsible for cleaning church • Locking up the building	**June 2014- Oct 2016**

SKILLS

▪ MATLAB ▪ Bobcat	▪ Microsoft Office ▪ Labview ▪ Simulink	▪ SolidWorks ▪ AutoCAD

RELEVANT COURSEWORK

▪ Engineering Design and Solid Modeling	▪ Calculus I, II, & III ▪ Statics	▪ Physics I & II ▪ Dynamics

▪ Engineering Programing with MATLAB ▪ Mechanics of Materials ▪ System Dynamics ▪ Mechanical Design I & 2	▪ Thermodynamics I ▪ Differential Equations ▪ Fluid Dynamics ▪ Heat Transfer ▪ Vehicle Engineering ▪ Mechanical Vibrations	▪ Structures and Properties of Materials ▪ Experimental Measures and Instrumentation ▪ Finite element analysis

KYLE L. WILSON

203 Russ Engineering Center, Wright State University wilson.759@wright.edu (740) 463-6646

EDUCATION

Bachelor of Science in Mechanical Engineering Wright State University, Dayton, Ohio • GPA 3.19/4.0	**May 2019**

WORK EXPERIENCE

Engineering/ Environmental Intern **City of Dayton, Aviation Department, Dayton, OH** • Update documents and assist in engineering calculations	**Aug 2018-Present**
Library Student Assistant **Wright State University, Dayton, OH** • Assist students and patrons with research and answer other various questions	**Jan 2016-Present**
Product Data Management Intern **Clopay Building Products, Troy, OH** • Update and release engineering documents and specifications. • Create 2D CAD models	**May 2017- Aug 2017**

SKILLS

▪ MATLAB ▪ ANSYS Fluent	▪ Microsoft Office ▪ Multisim	▪ SolidWorks ▪ Labview

▪ Working Model	▪ Simulink	▪ AutoCAD

RELEVANT COURSEWORK

▪ Engineering Design and Solid Modeling ▪ Engineering Programing with MATLAB ▪ Mechanics of Materials ▪ System Dynamics ▪ Mechanical Design I	▪ Calculus I, II, & III ▪ Statics ▪ Thermodynamics I & II ▪ Differential Equations ▪ Fluid Dynamics ▪ Heat Transfer ▪ Vehicle Engineering ▪ Compressible Fluid Flow	▪ Physics I & II ▪ Dynamics ▪ Structures and Properties of Materials ▪ Experimental Measures and Instrumentation ▪ Computational Methods for Mechanical Engineers

17 APPENDIX D – ETHICS STATEMENT AND SIGNATURES

Wesley Eidt

Jake Erwin

Bradley Franks

Ryan Kinkade

Kyle Wilson

Scanned by CamScanner

18 APPENDIX E – Washing Machine Manual

Washing Machine Instruction Manual

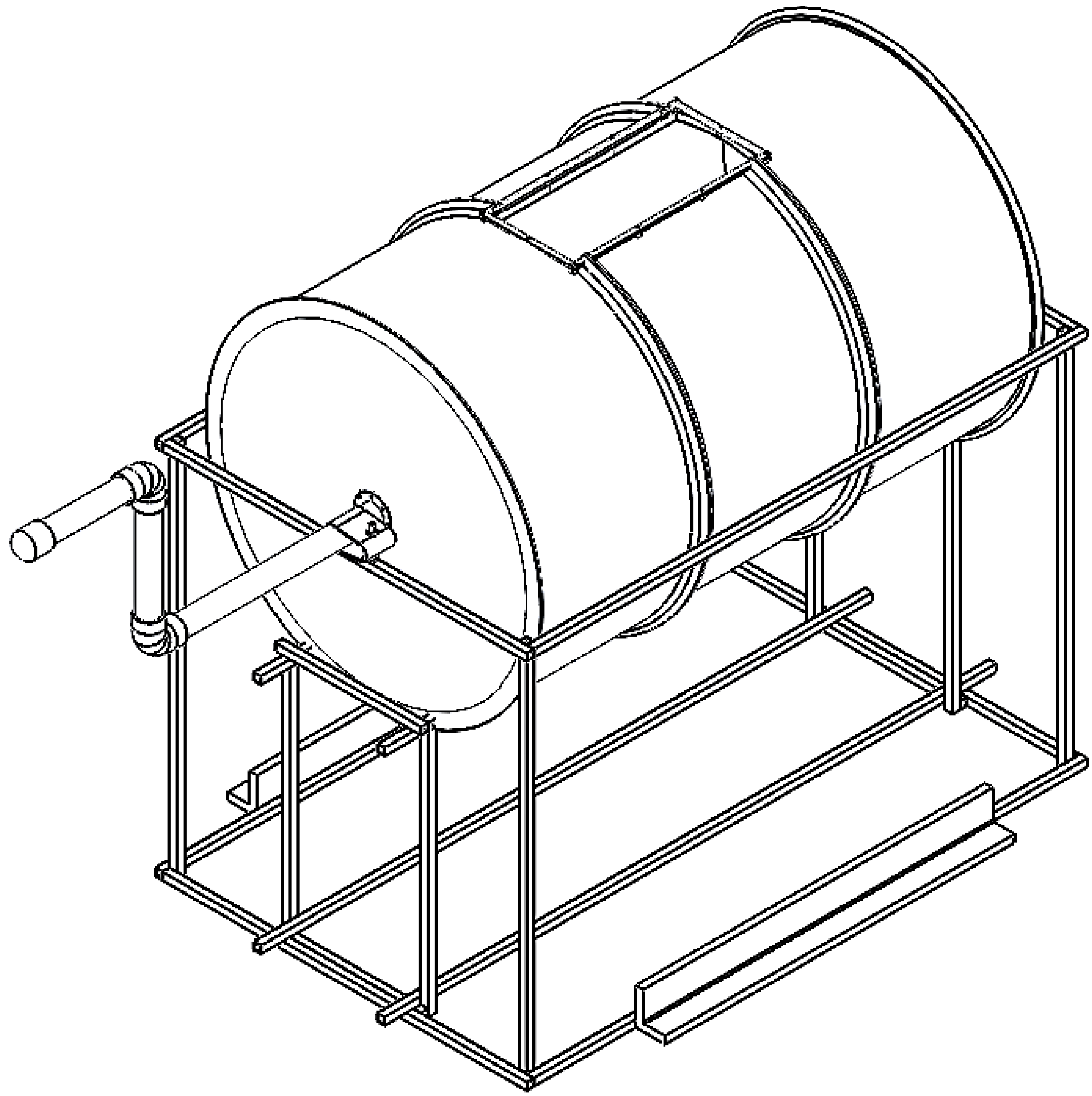


Table of Contents

Total Bill of Materials

Item	Quantity
13 mm Steel Tubing	17 m
Rubber Inner Tube	2 m
55 Gallon Drum	1
6.35 mm Bolts 7.75 cm	2
6.35 mm Bolts 5 cm	10
6.35 mm Hex Nuts	24
55 mm PVC Pipe	0.5 m
25 mm PVC Pipe	5 m
25 mm PVC 90° Elbows	10
25 mm PVC T-Joint	8
25 mm PVC Cap	2
2.5 mm Blots or Screws	36
2.5 mm Hex Nuts	36
Angle Iron	120 cm

Supplemental Instructions:

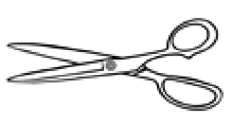
General:

The brush-and-tub symbol used throughout the instructions represents the use of PVC glue. A combination of primer and glue is recommended for most effectively attaching PVC components.

The welding symbol is used wherever metal tubing needs attaching.

The boiling symbol is used to indicate that a piece of PVC needs to soak in boiling water. This allows the pipe to be easily deformed.

The pinching symbol indicates that a piece of PVC needs re-formed via squeezing. An effective way to do this is by sliding a smaller diameter PVC tube through the bearing and pinching until snug.



The cutting symbol indicates that a piece requires incision. This is used for instances of cutting and hole puncturing in the barrel or in a piece of PVC. Any appropriate tool can be used. Holes for bolts are recommended to be 0.375” (10 mm) for the 0.5” (6.35 mm), but any size hole can work as long as it provides a snug fit for the bolt.

Agitator:

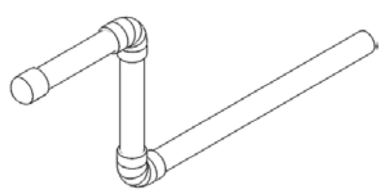
All PVC pieces used in the construction of the agitator are 1” (25 mm) diameter. The elbows and T-corner pieces should all be flush when assembled. The fins should ideally be offset 90 degrees from each other, one in each cardinal direction. The holes in either end of the shaft are for bolts that increase replaceability of each of the PVC components.

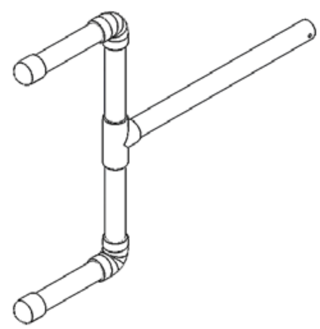
Bearings:

The bearings are created by boiling short segments of 2” (55 mm) diameter PVC. After a few minutes, they should be pliable enough to reform by hand. Care should be taken when dealing with hot water and PVC.

Hand Crank:

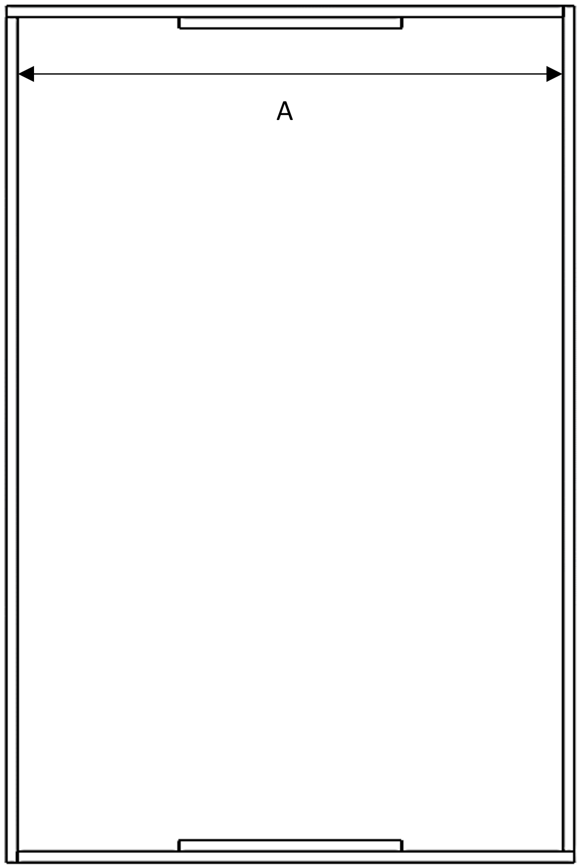
The handle used to rotate the agitator can be made in any shape that the user feels will be easiest to operate. The only restriction is that the hand crank be able to attach to the agitator through the axial hole in the barrel. Some potential handles are shown below.

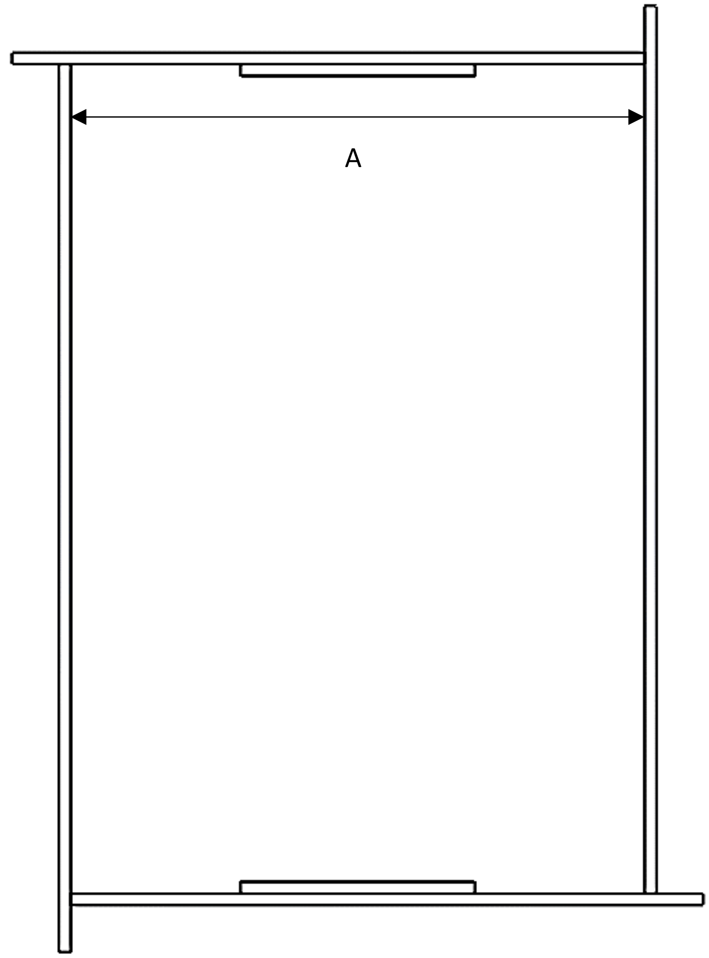




Frame:

All metal tube pieces can be several centimeters longer than indicated. The length values listed in the instructions are minimum values. The exceptions to this are the vertical, 17” (43.2 cm) pieces, labelled “B” in the manual. These should be as close to the indicated value as reasonably possible. The critical dimensions for the construction of the frame are the inside dimensions when attaching tubes together, which should be measured as closely as possible. All metal pieces attach at 90-degree angles. The images below show how the frame can be constructed using pieces longer than shown. The distance “A” is the same in both images.





Drum:

The sharp edges created from cutting in steps 1 and 2 need to be covered with rubber. They are covered by single or multiple pieces of rubber. In all steps where rubber is applied, the bolt heads are to be on the inside of the barrel. This means that the threads of the bolts and the corresponding nuts will be on the outside of the barrel.

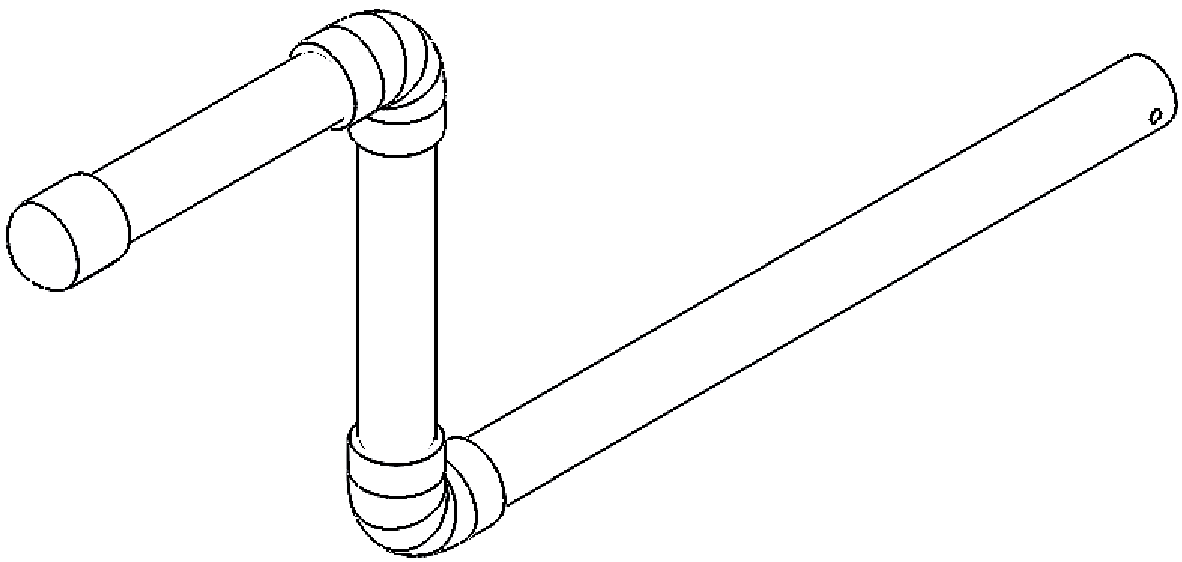
Assembly:

The bolts welded to the frame should be oriented so that the threads are facing up and the head is touching the frame. There are two nuts on this bolt, one on either side of the PVC bearing to hold the bearing in place without slipping. To insert the agitator, it must be rotated as it is lowered into the barrel. Once the agitator is inside the barrel, bolts and nuts can be inserted to connect it to the tail and the hand crank.

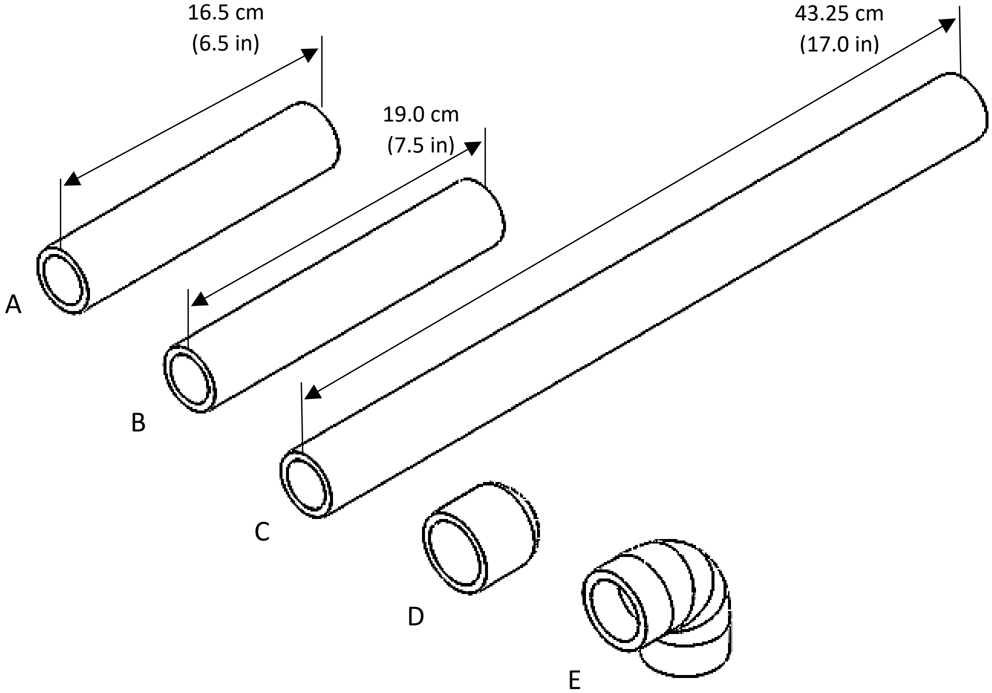
Plug:

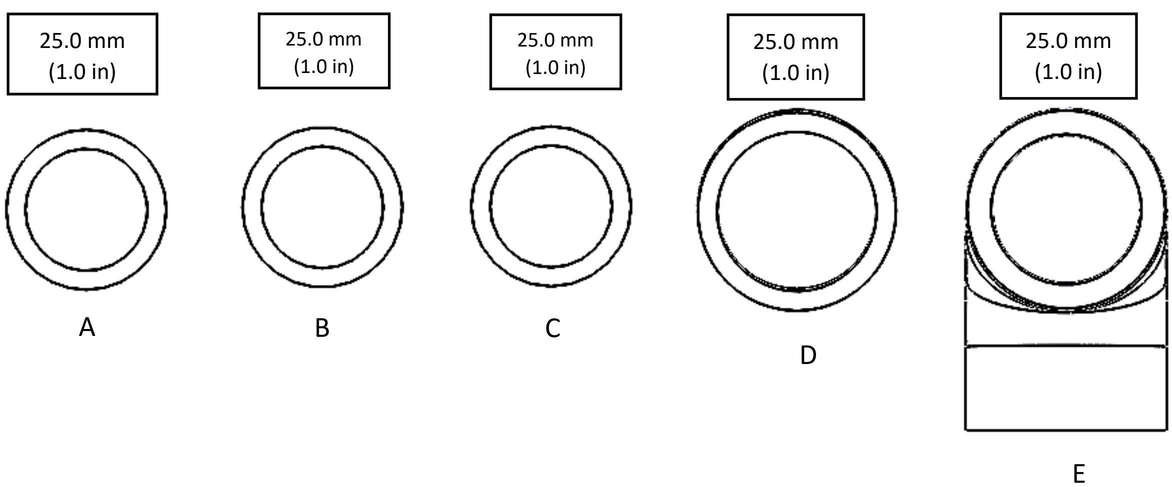
To attach the plug to the barrel, washers and bolts connect as shown in the manual. A piece of rubber is inserted between the barrel and the first washer to create a waterproof seal.

Hand Crank:



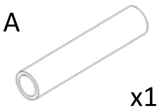
Bill of Materials:





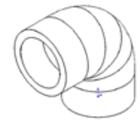
A	x1
B	x1
C	x1
D	x1
E	x2

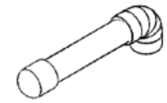
1)

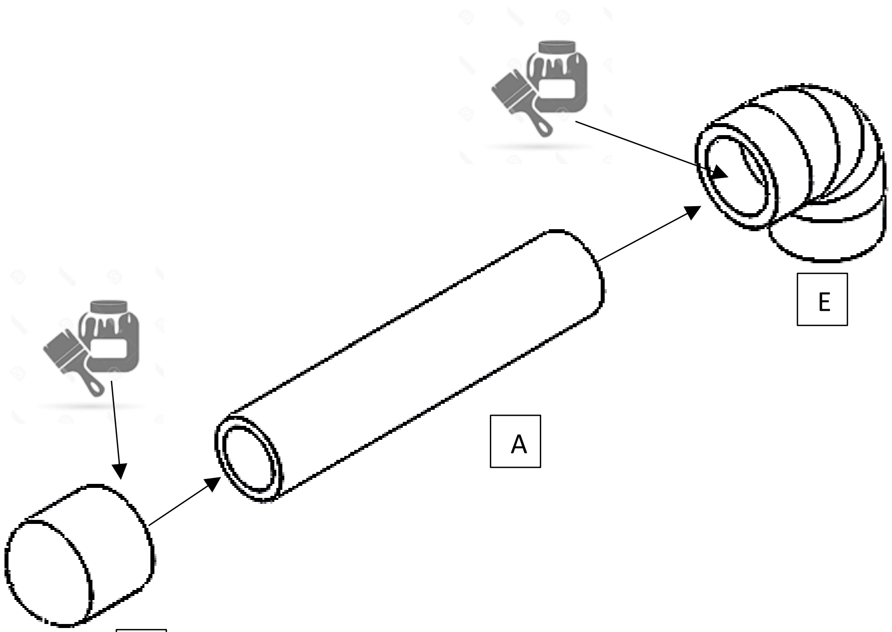
A

x1

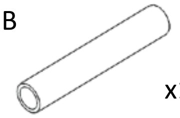
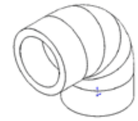
D

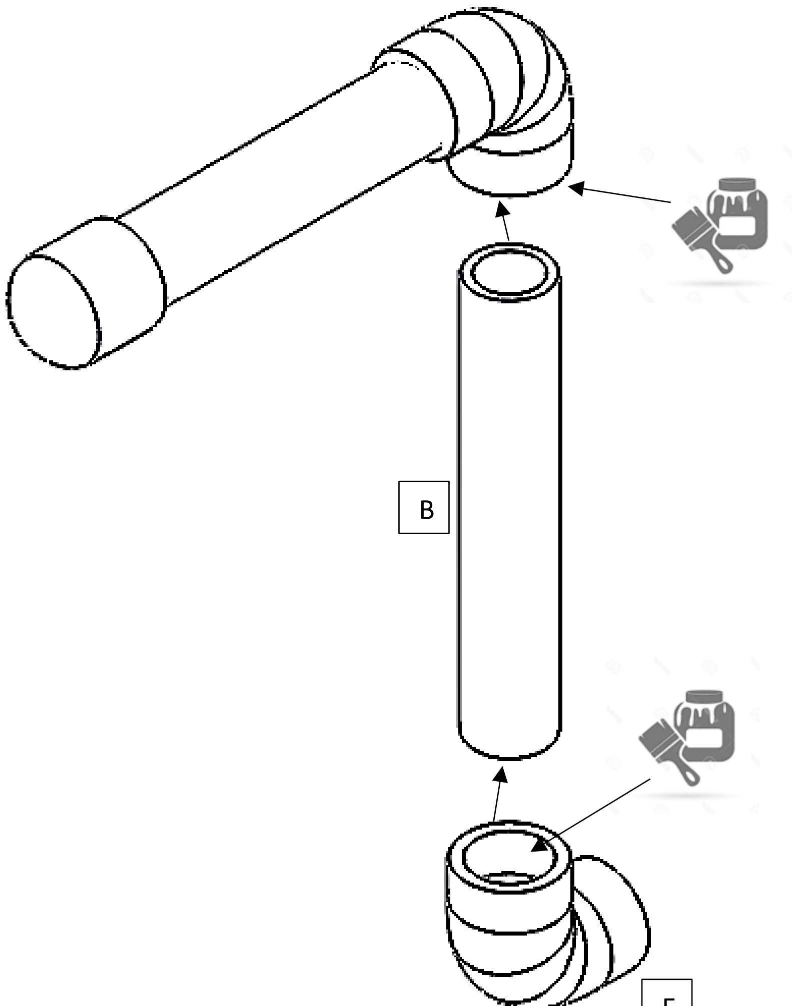
x1

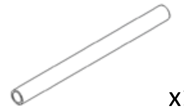
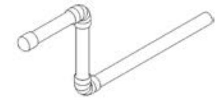
E

x1

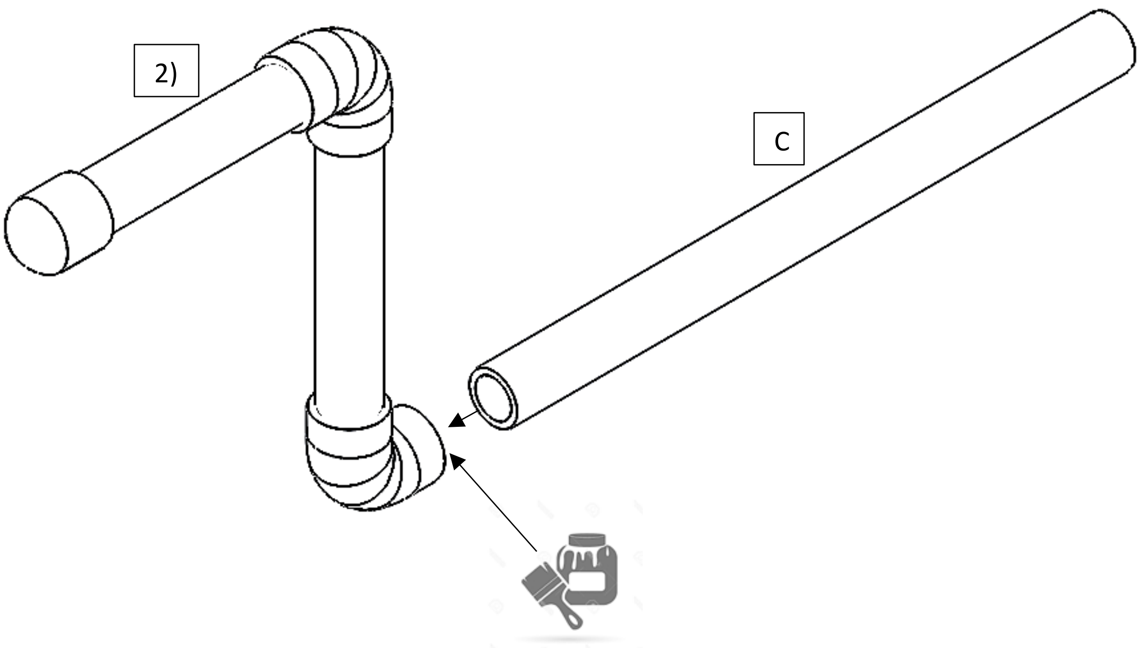




2)	B x1  E x1 	



3)		



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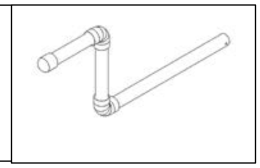
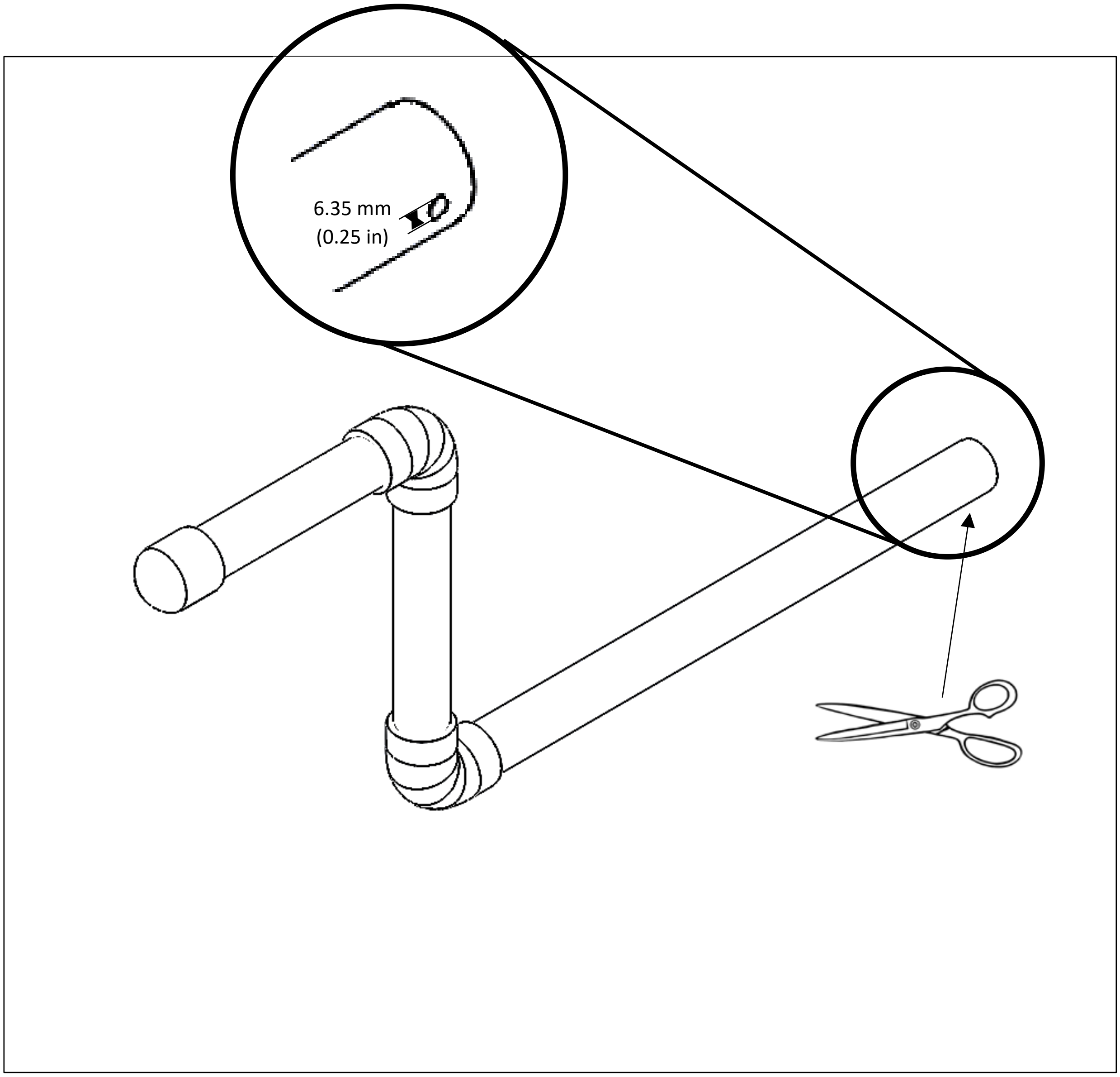
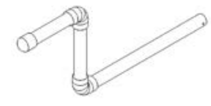
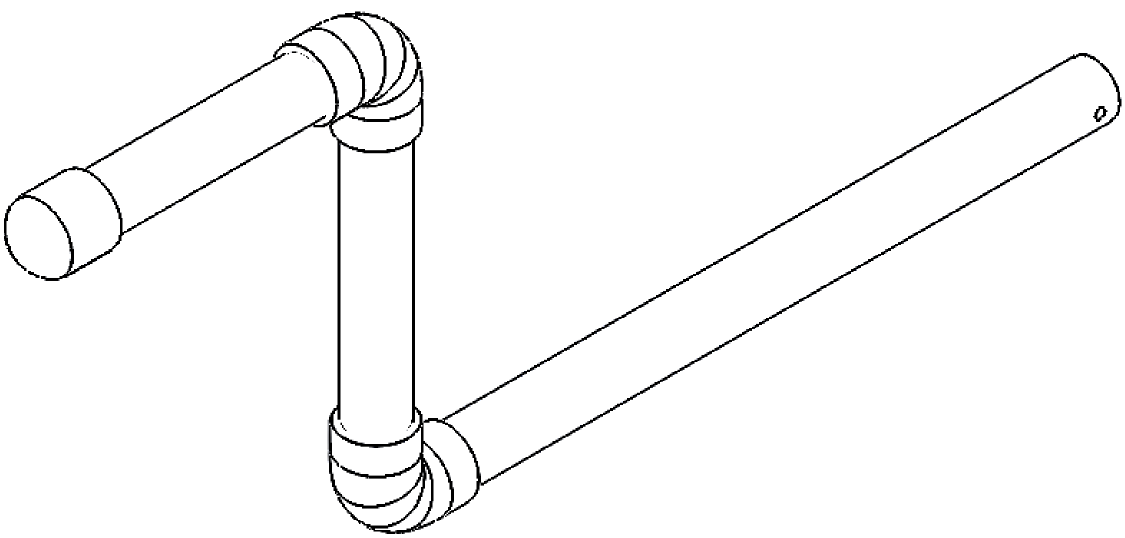
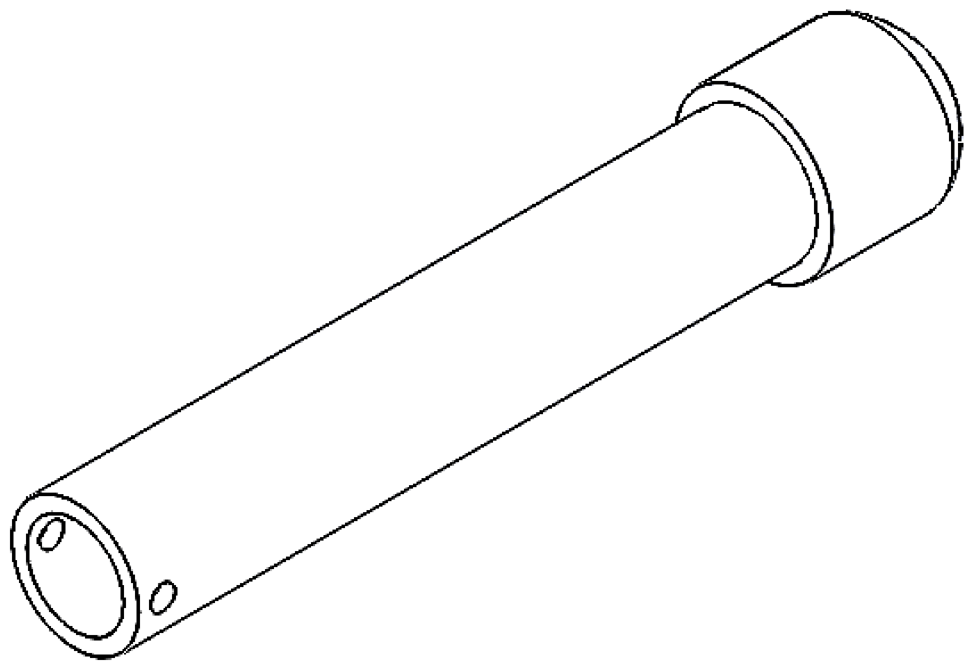




5)		



Support Tail:



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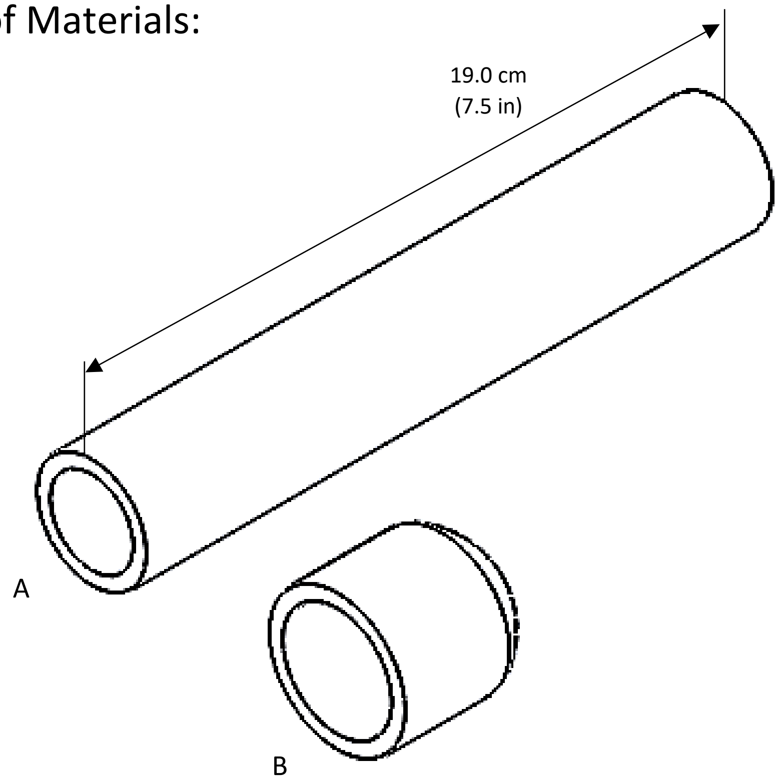
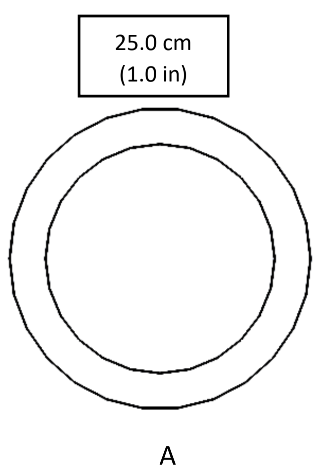
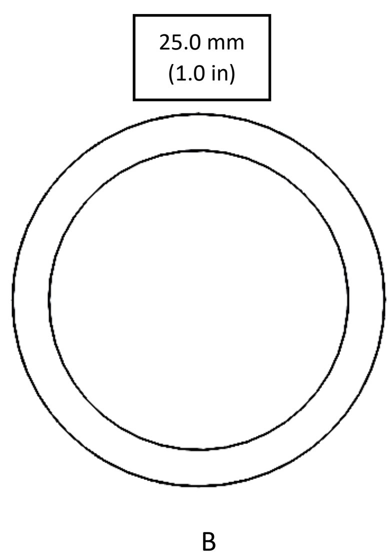
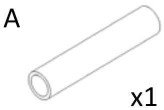
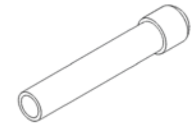
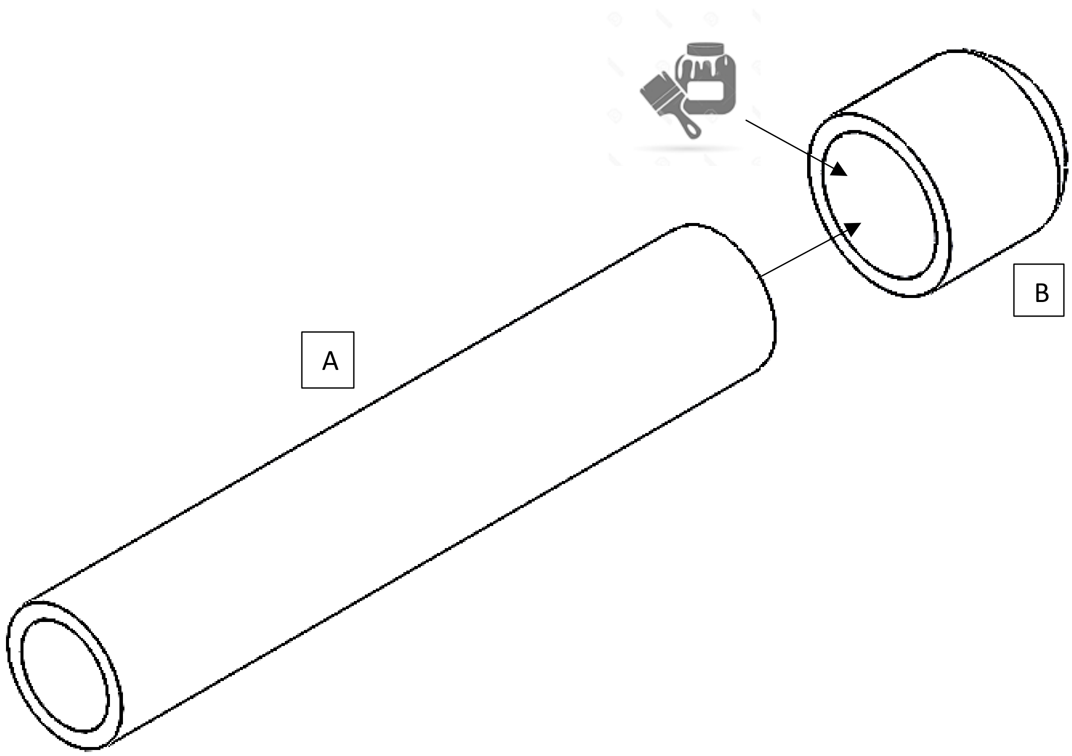


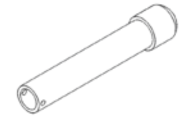


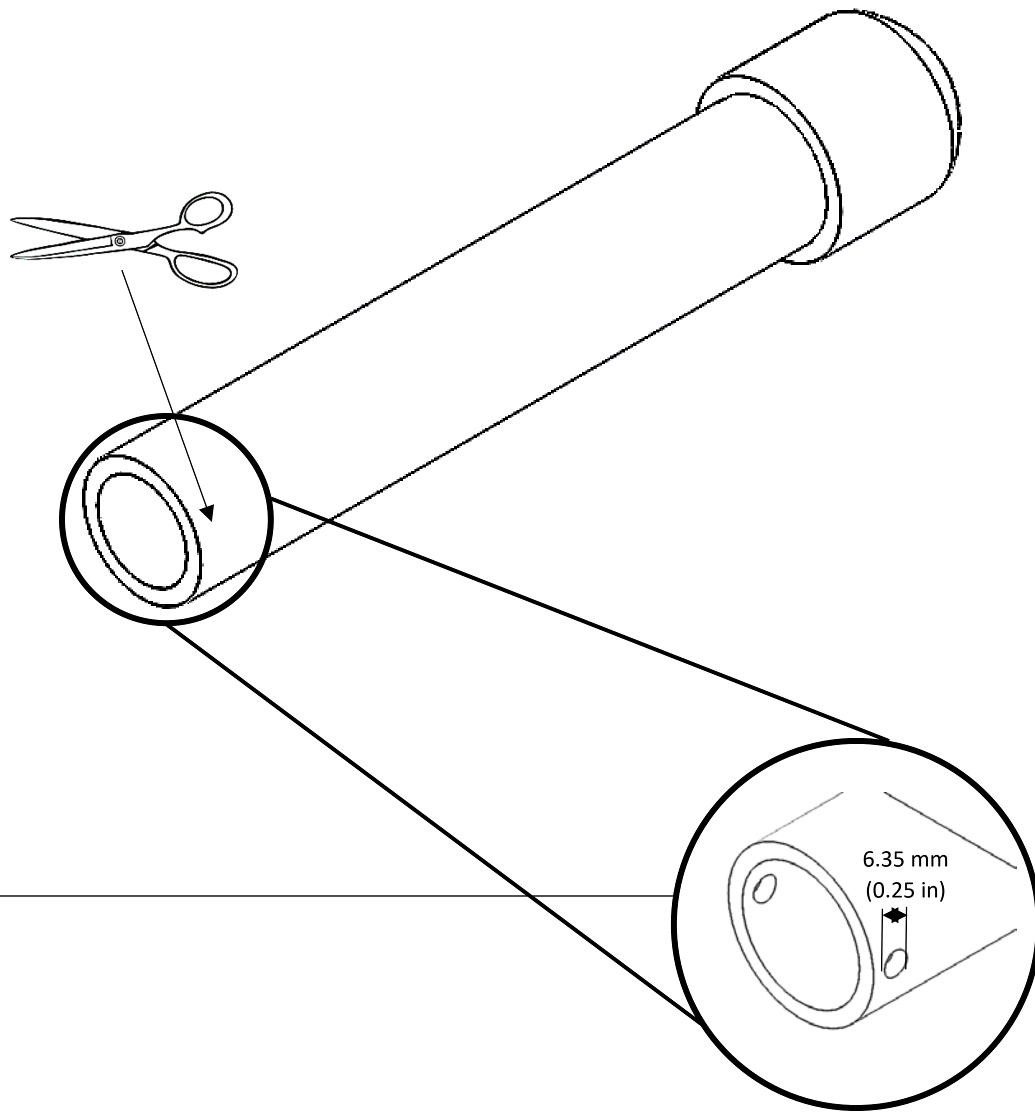


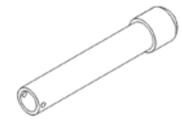
A	x1
B	x1

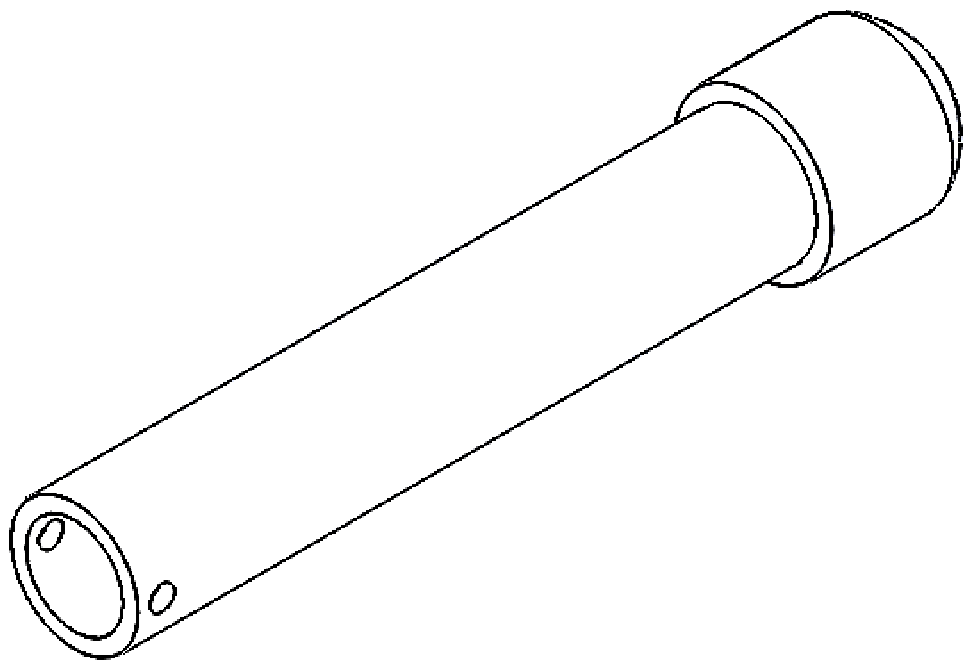
1)	A  x1 B  x1	



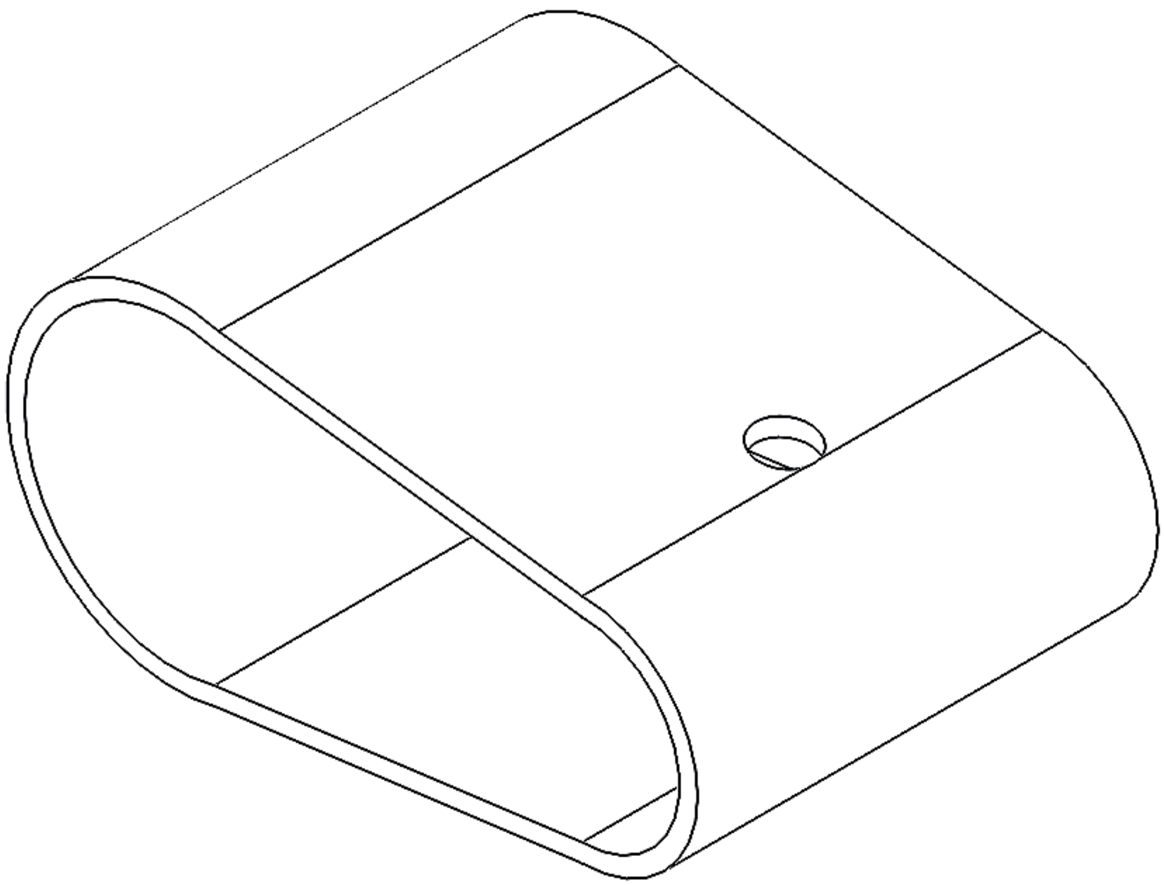
2)		



3)		



Bearing:



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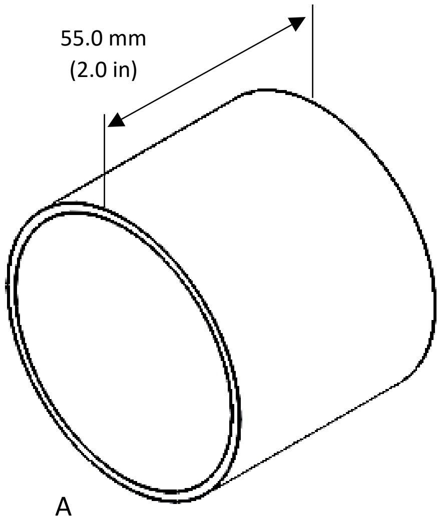
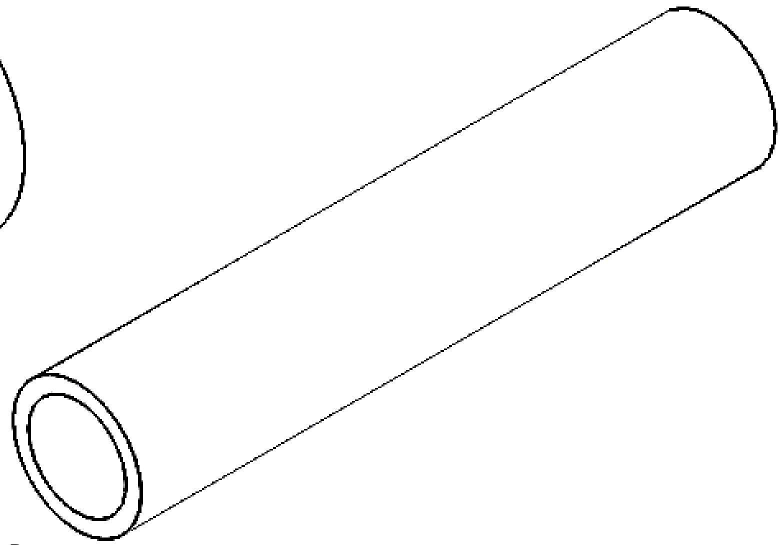
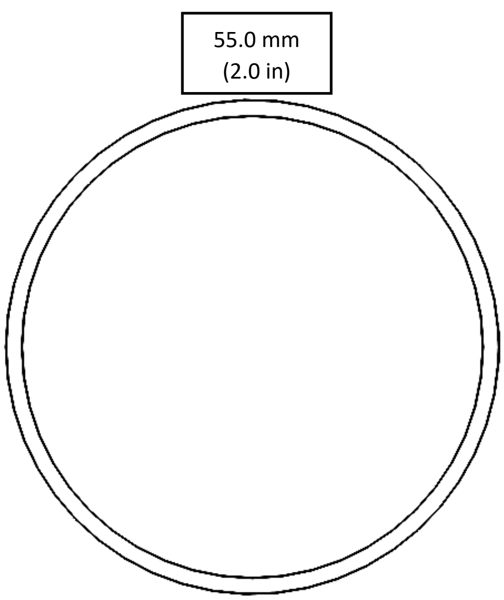


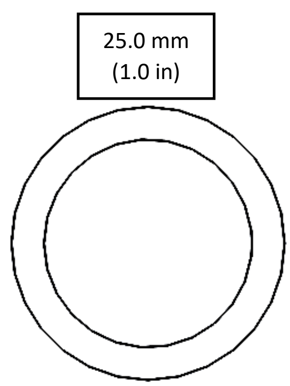
A



B



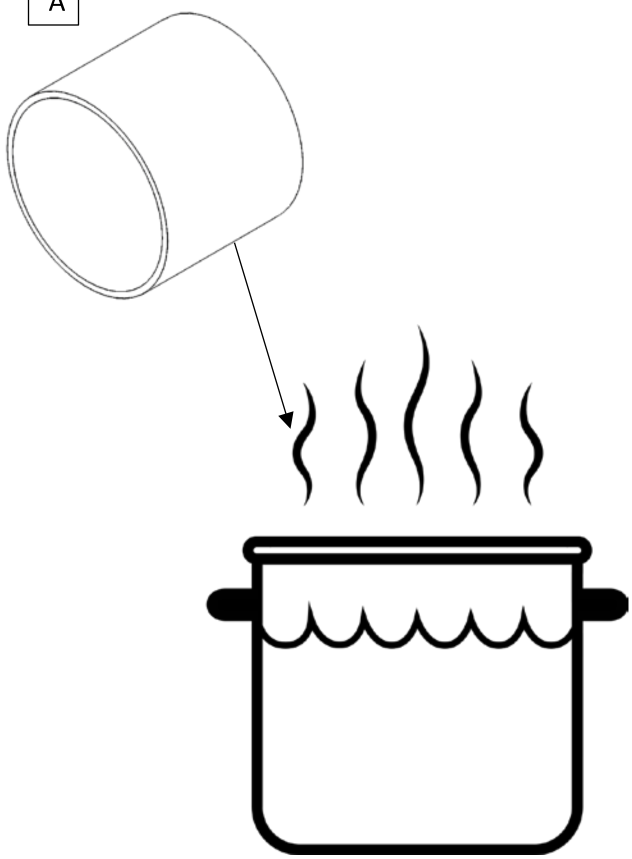
A

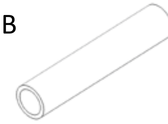
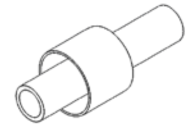


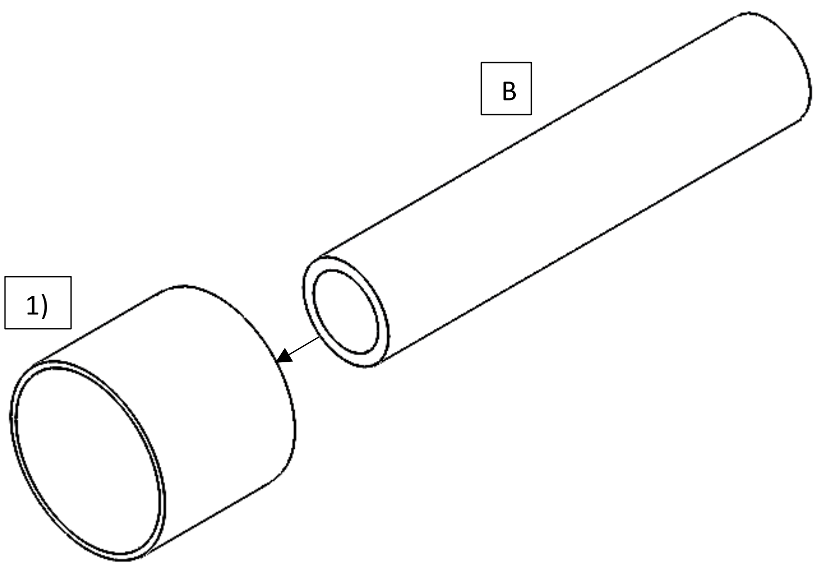
B

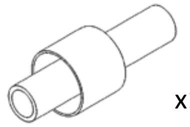
A	x2
B	x1

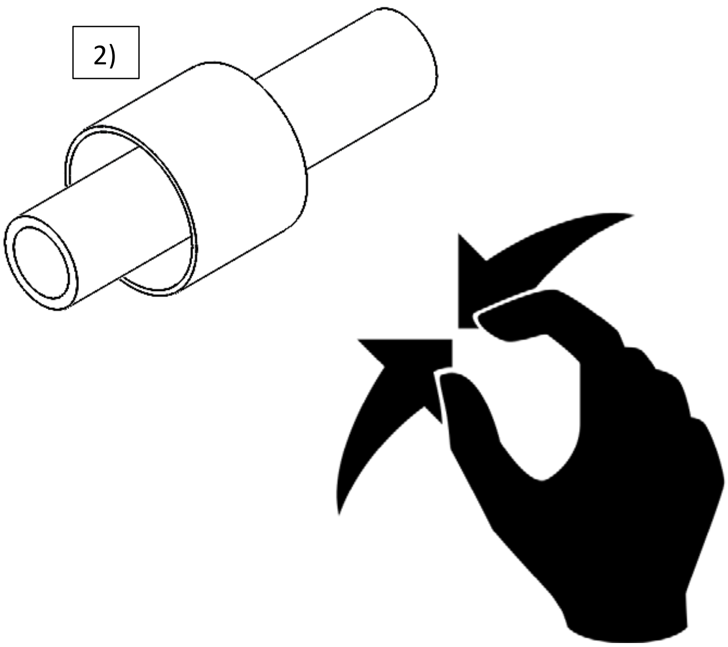
1)		

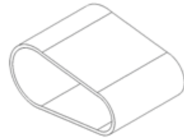


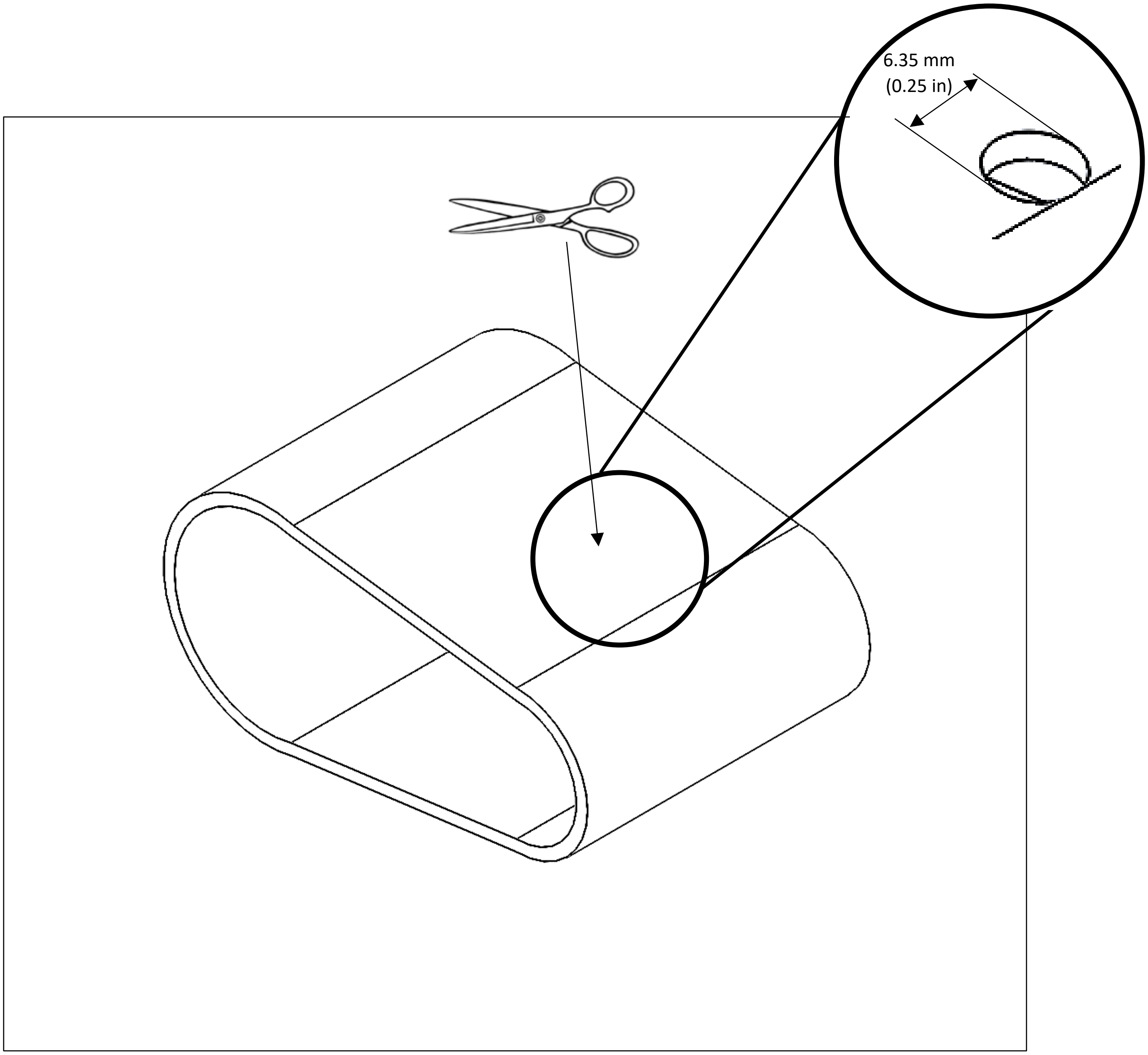
2)	1) 	x1	B 	x1	



3)	2)  x1	



4)	3)  x1	



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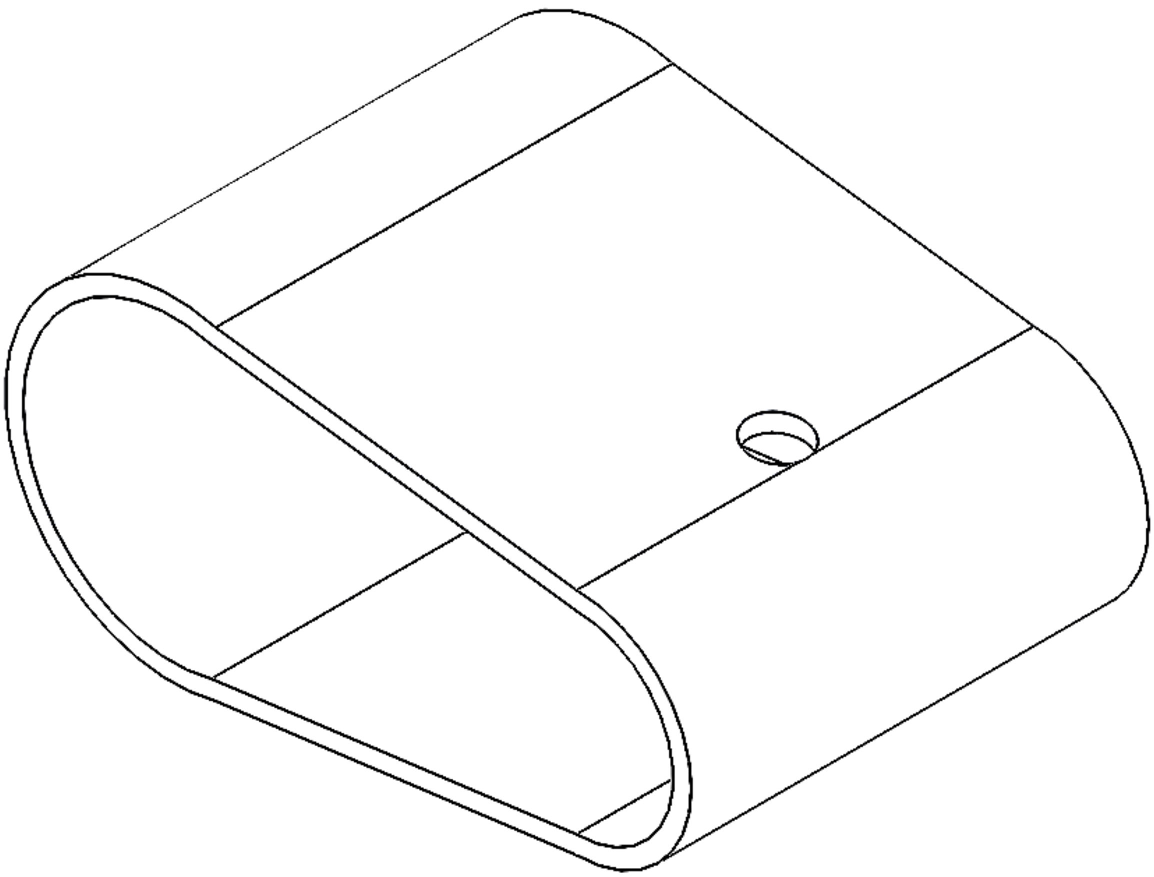
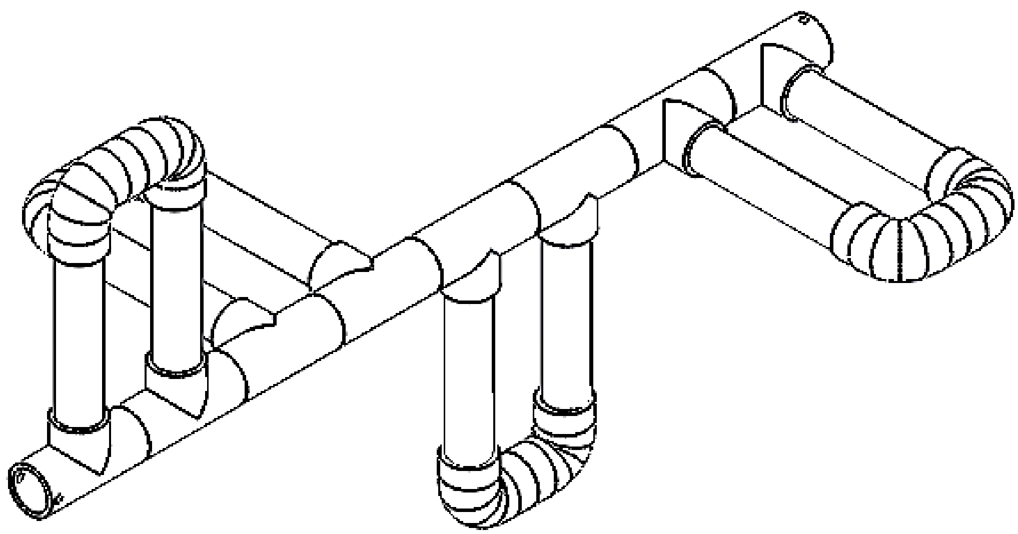
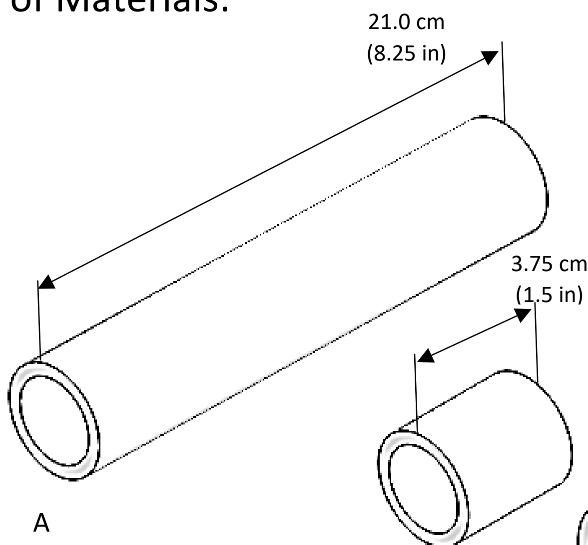


x2

Agitator:

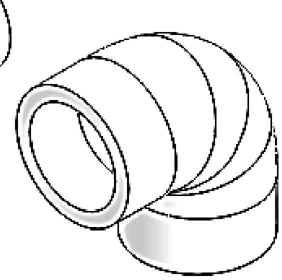


Bill of Materials:

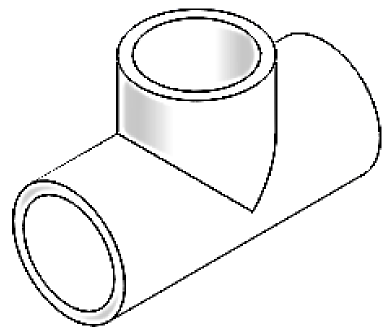


A

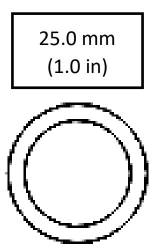
B



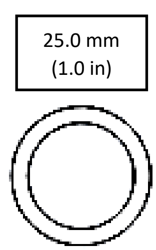
C



D



A



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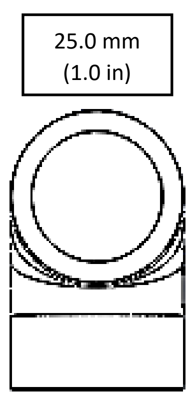
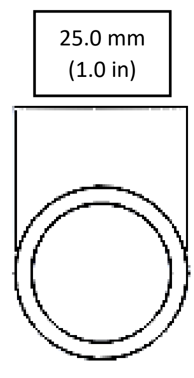
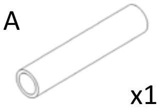
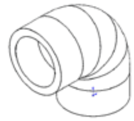
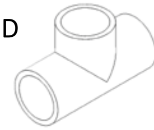


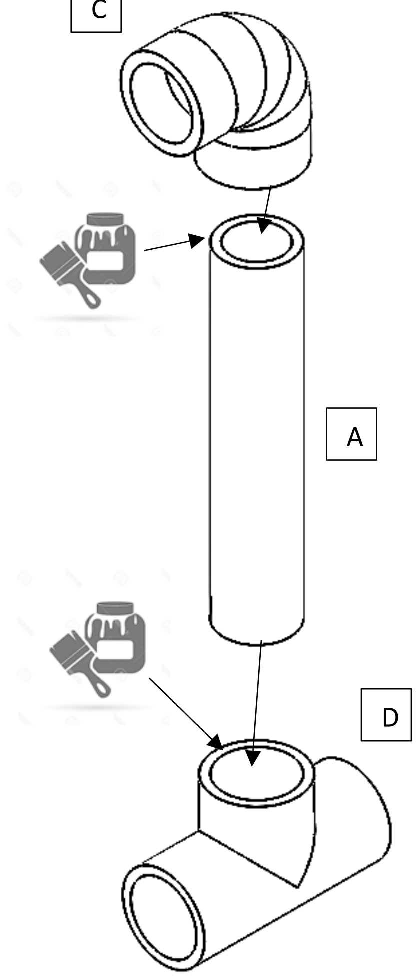
C

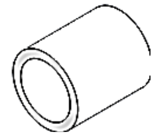


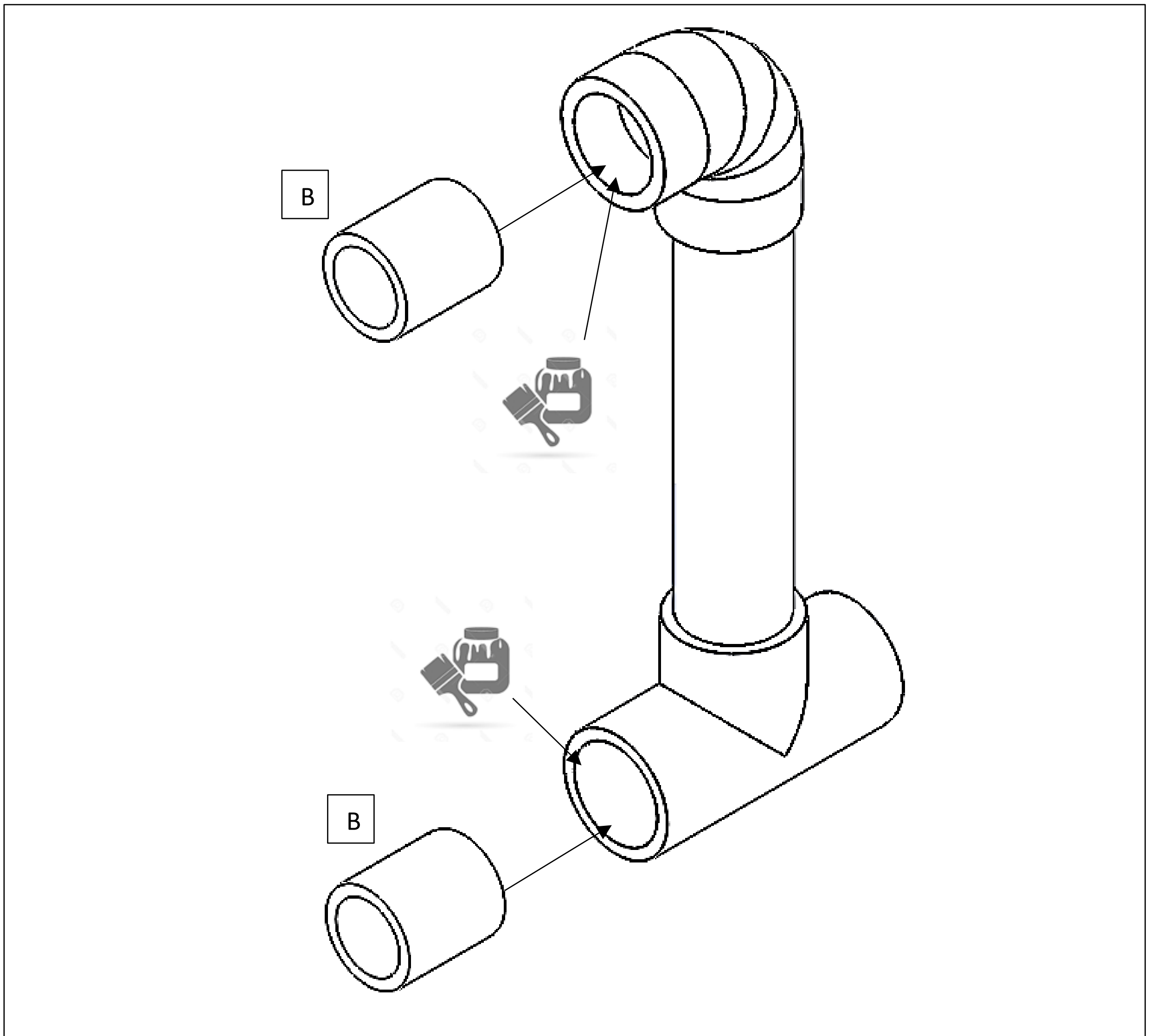
D

A	x8
B	x11
C	x8
D	x8

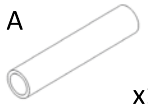
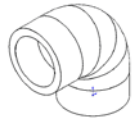
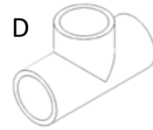
1)	A  x1	C  x1	D  x1	

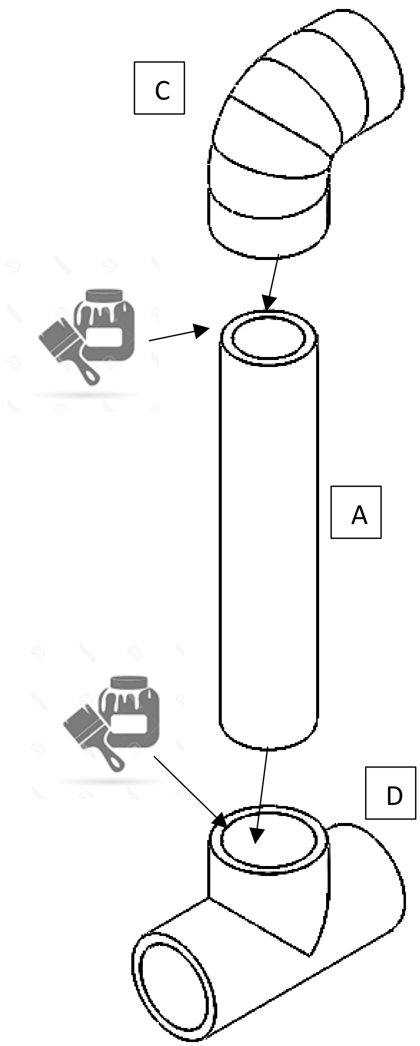


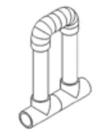
2)	B  x2	

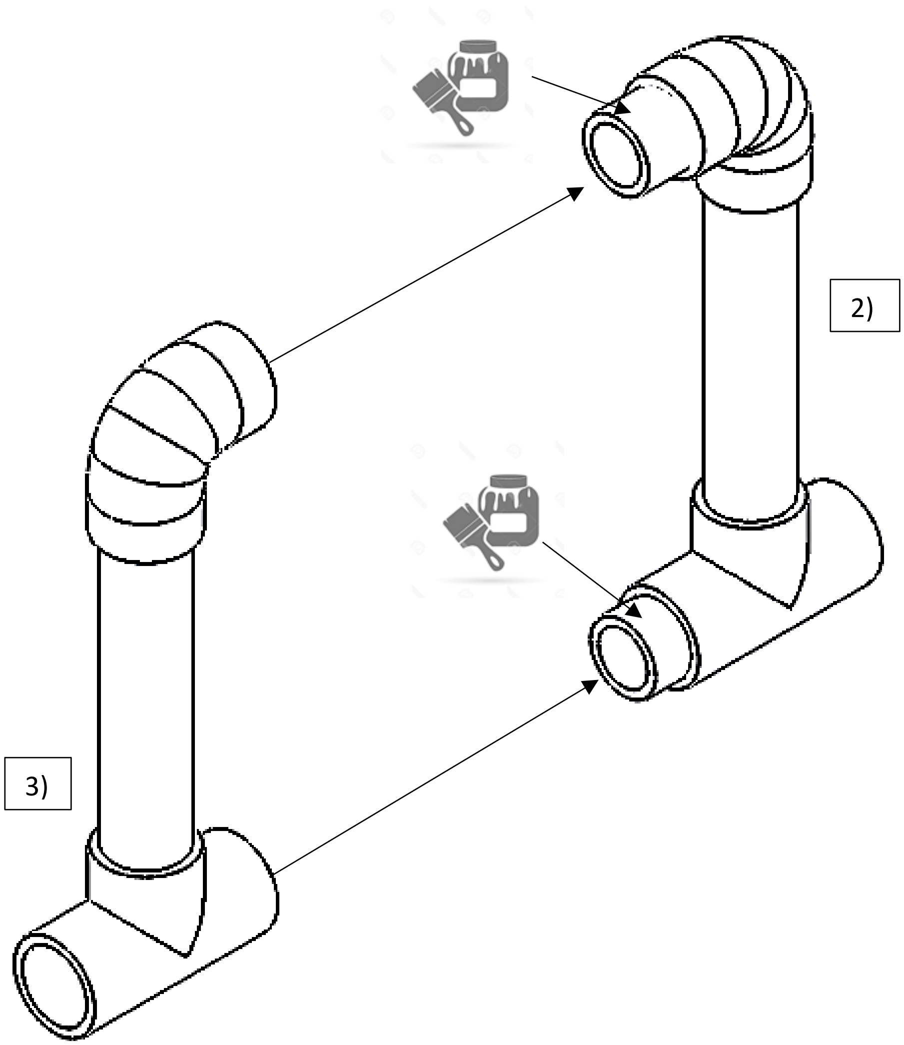


3)

A	C	D	
 x1	 x1	 x1	



4)	3)  x1	2)  x1	



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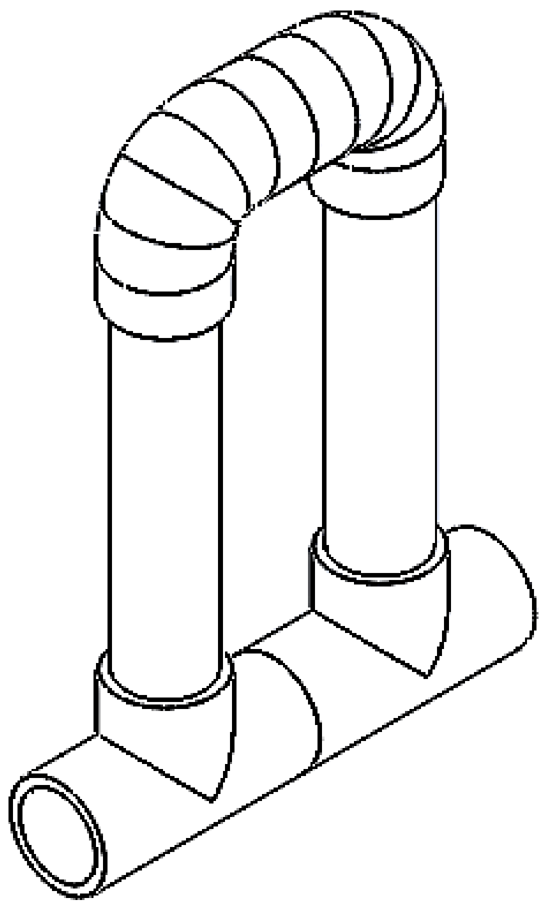
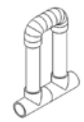
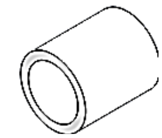
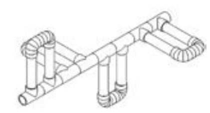
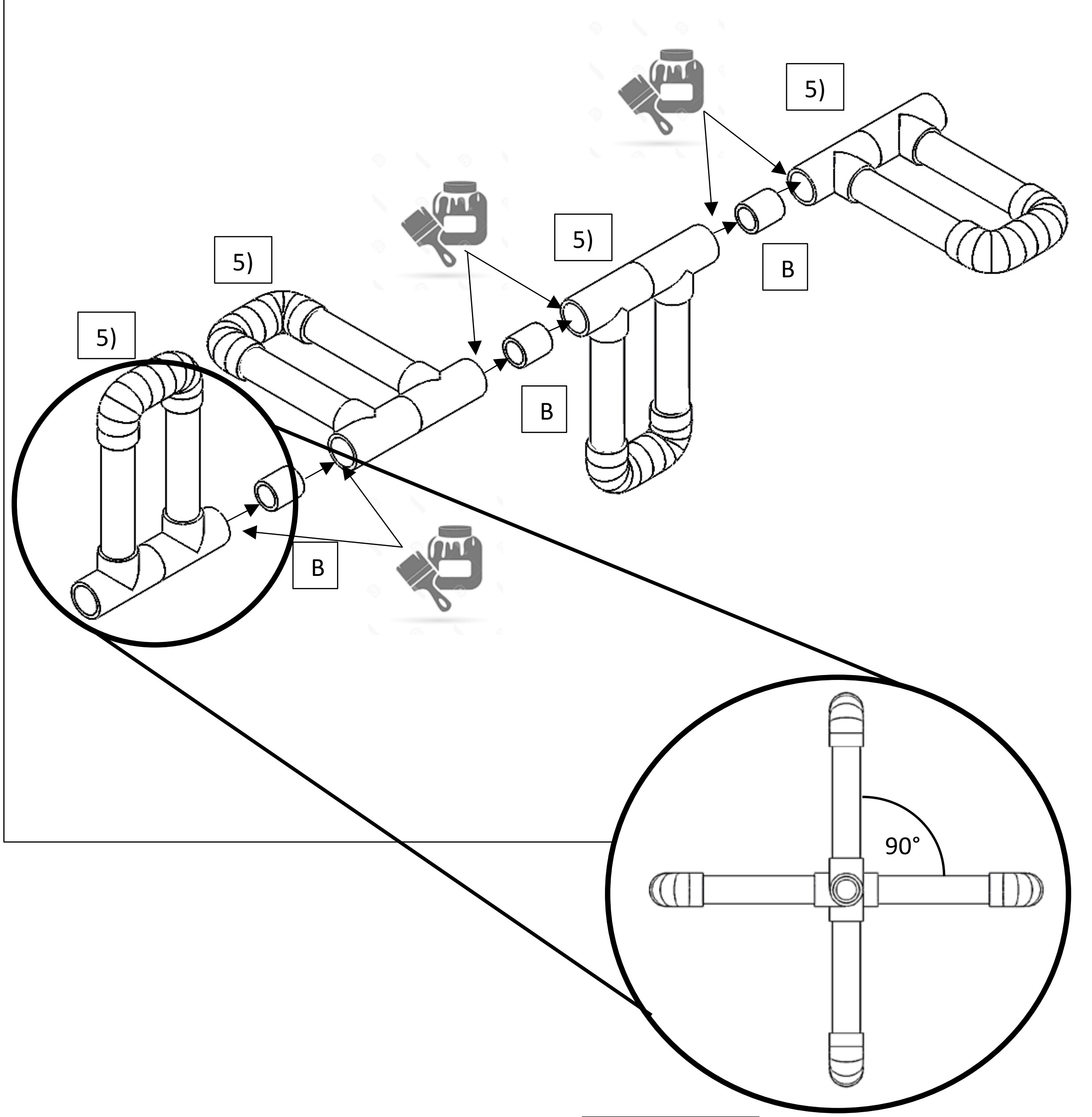
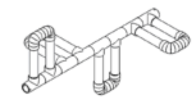
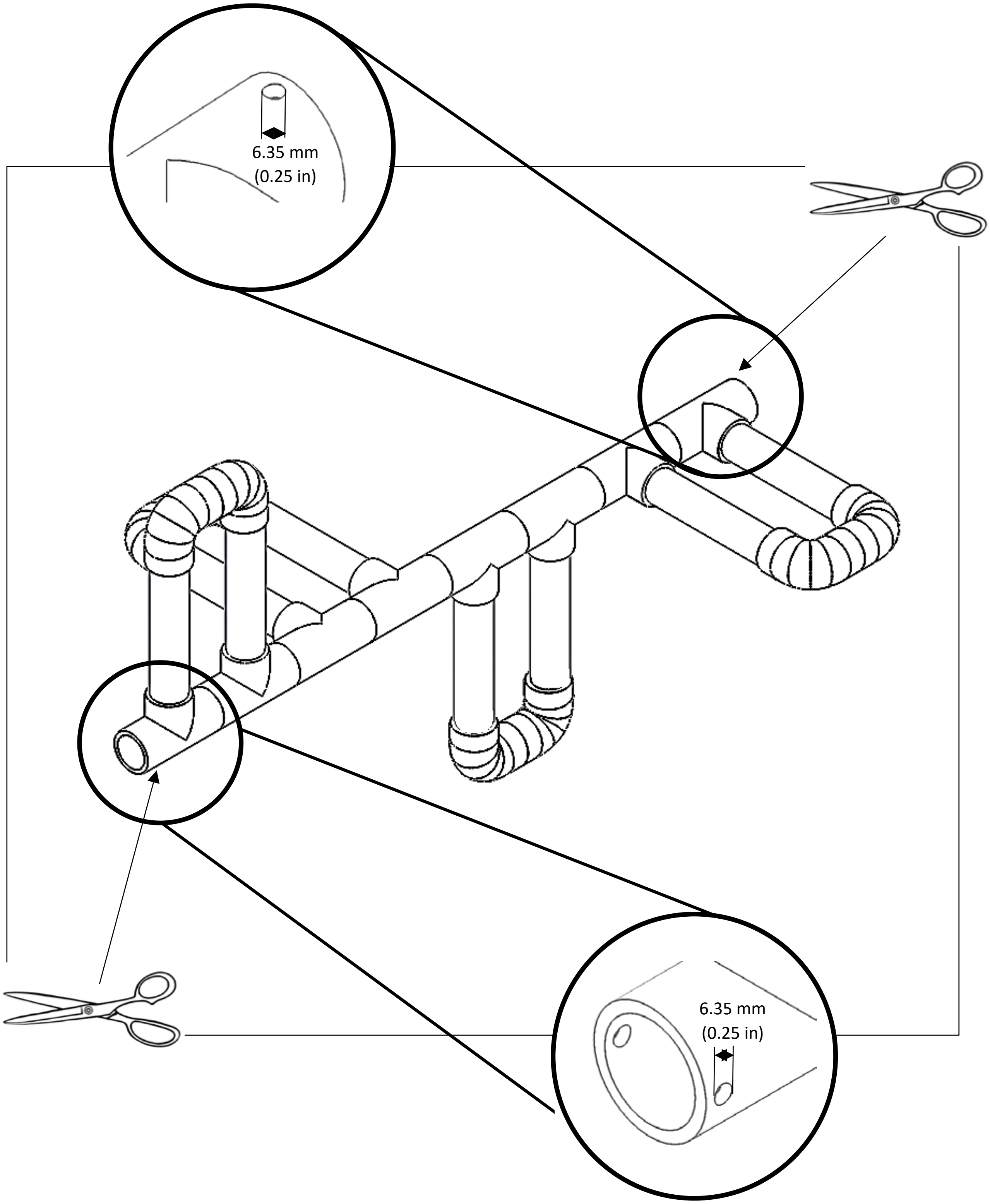


4x

6)	5)  x4	B  x3	



7)		



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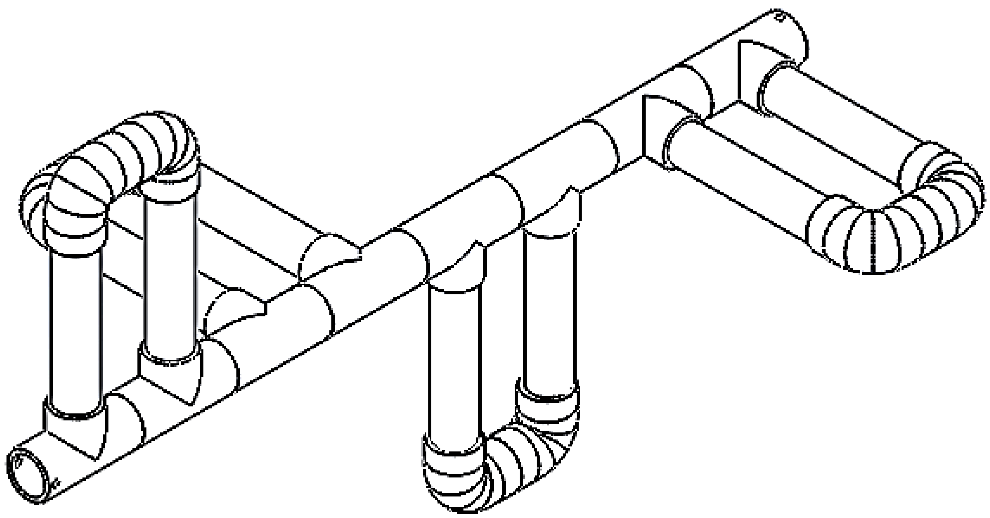
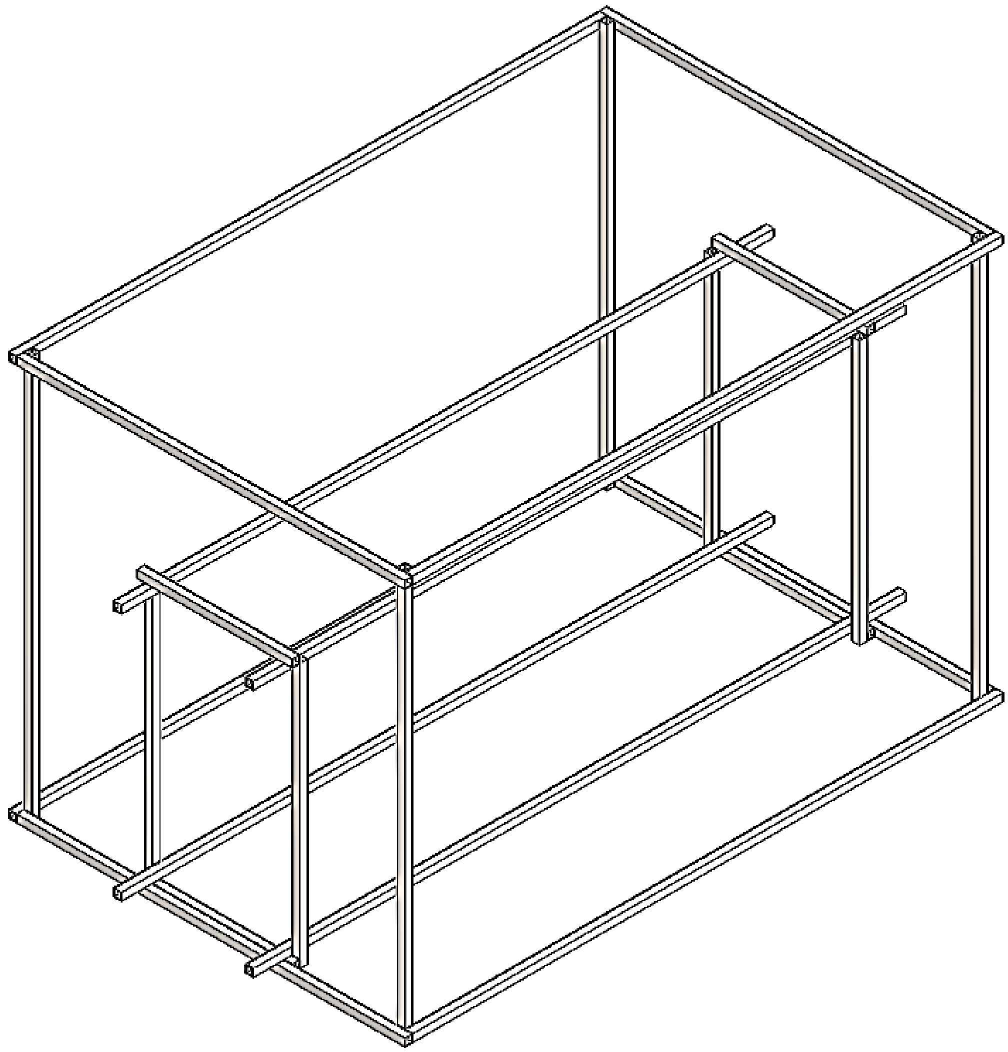
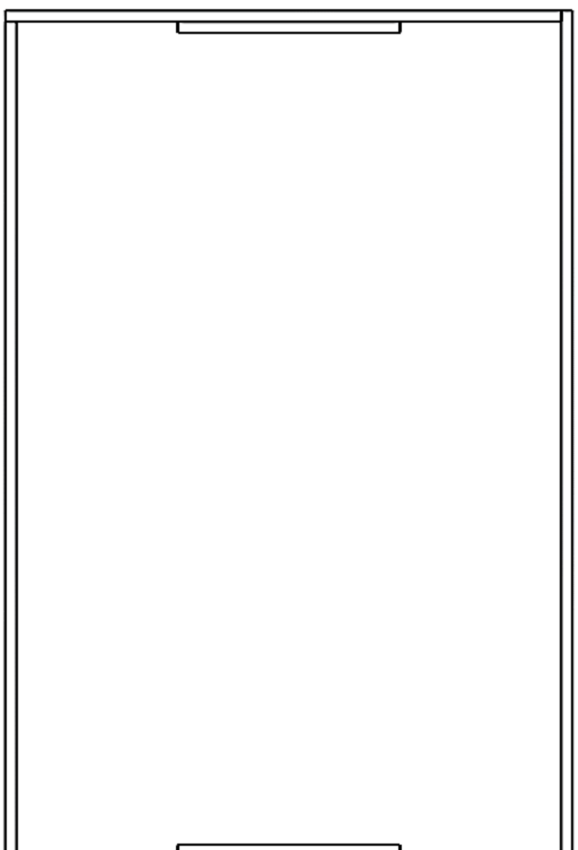
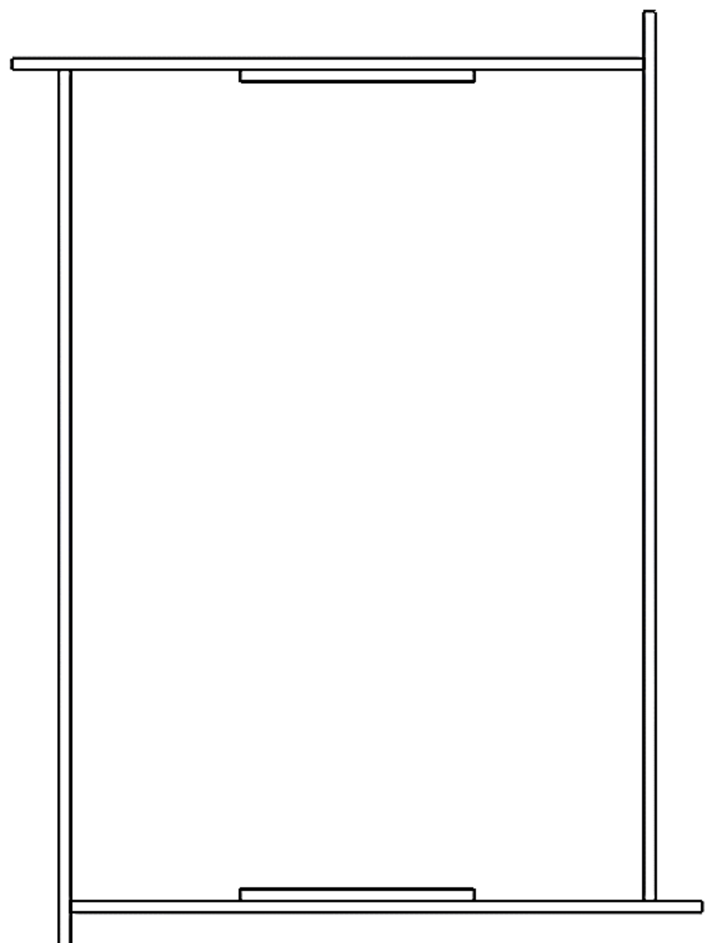


Frame:

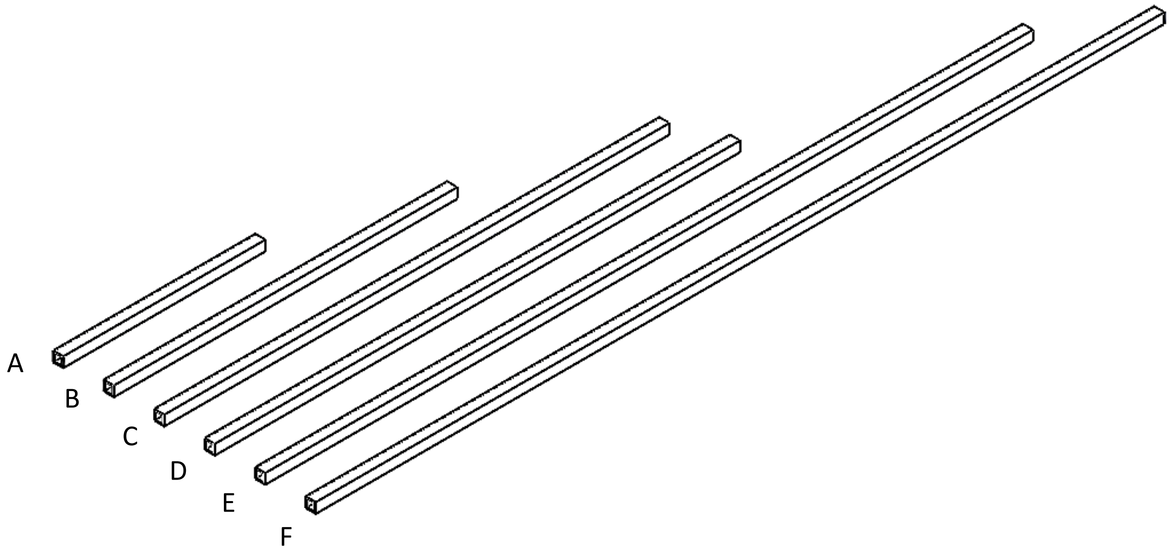


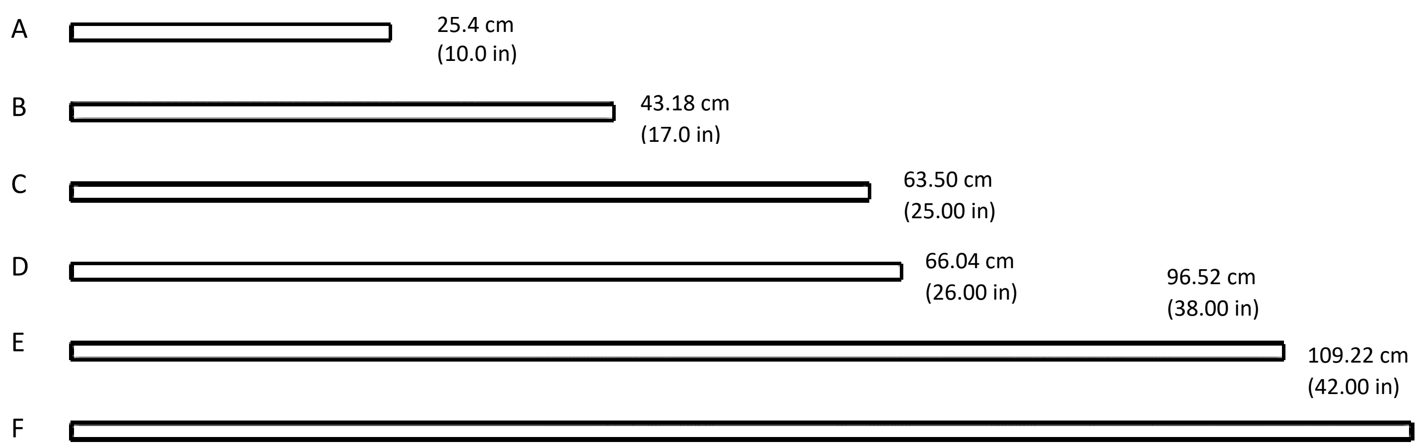
Instructions:

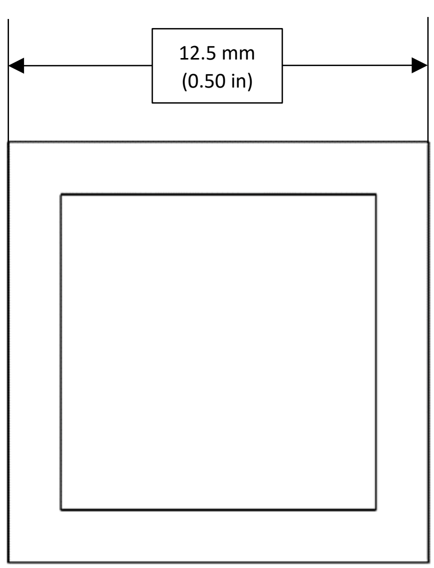




Bill of Materials:



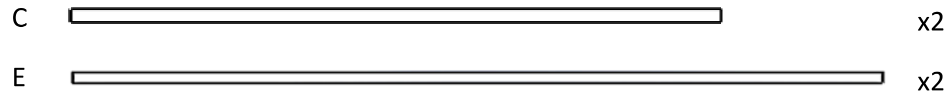


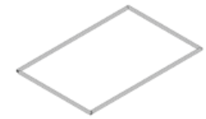


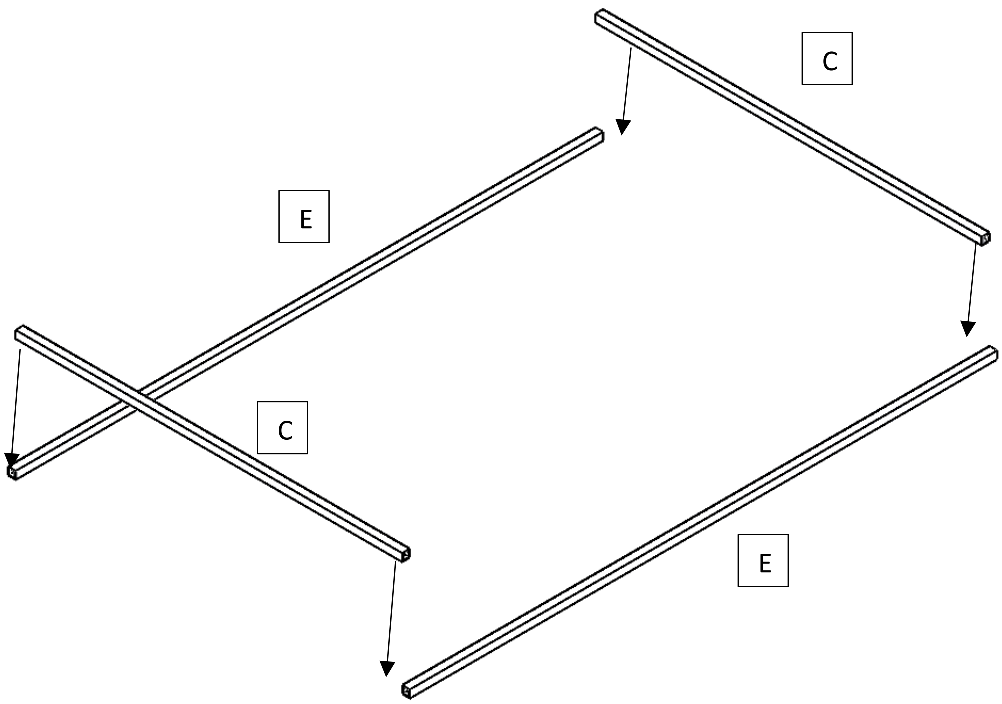
A, B, C,
D, E, F

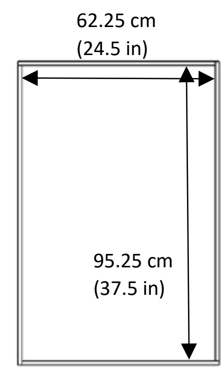
A	x4
B	x4
C	x4
D	x4
E	x4
F	x4

1)









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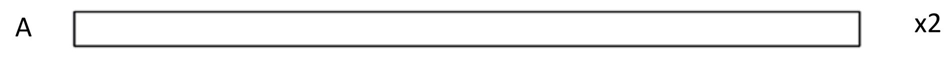

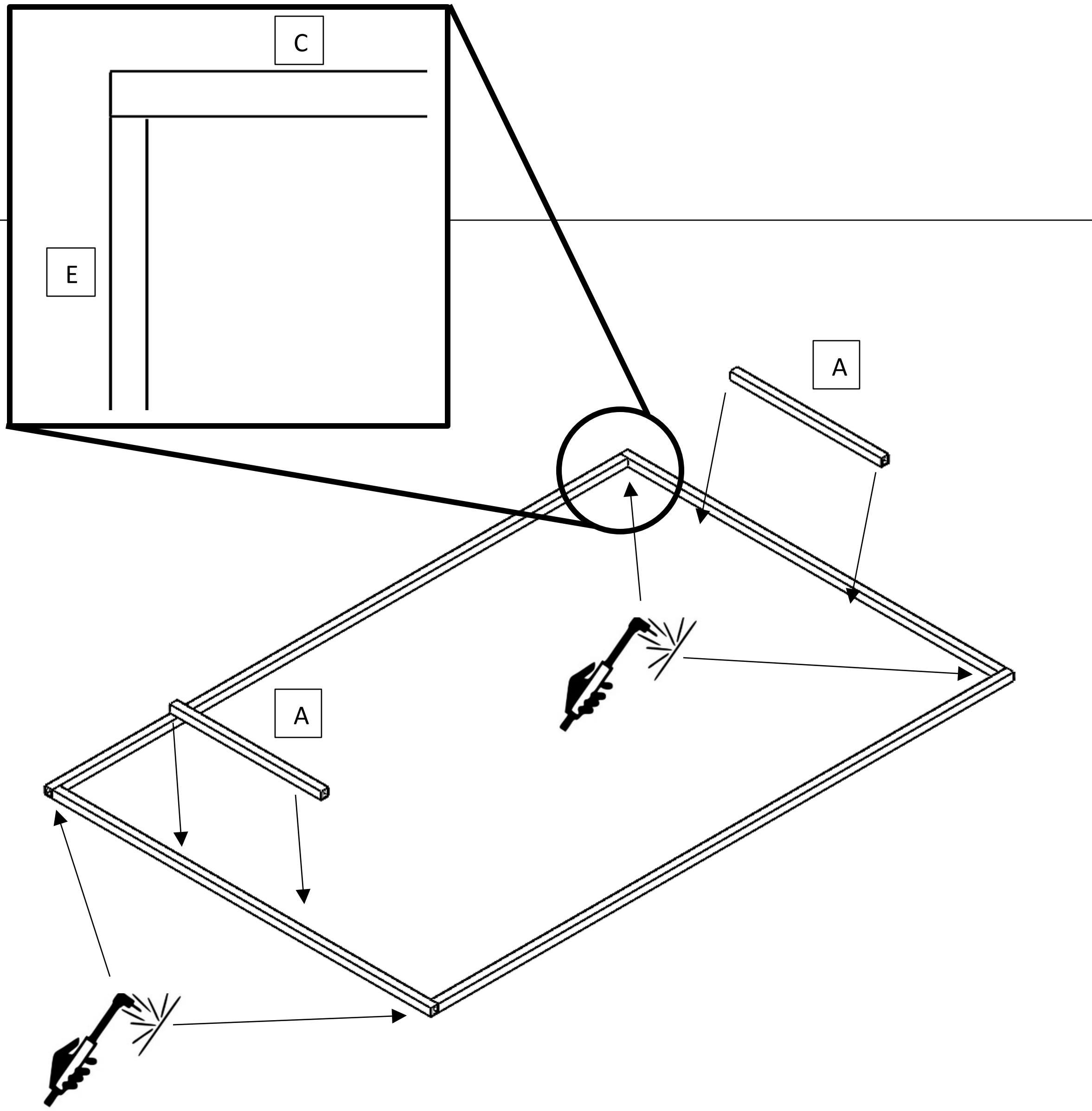

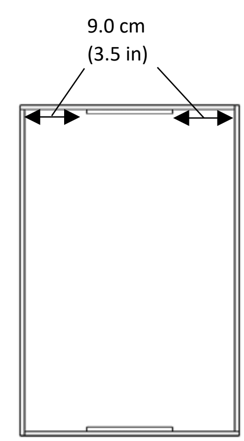

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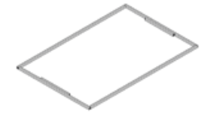
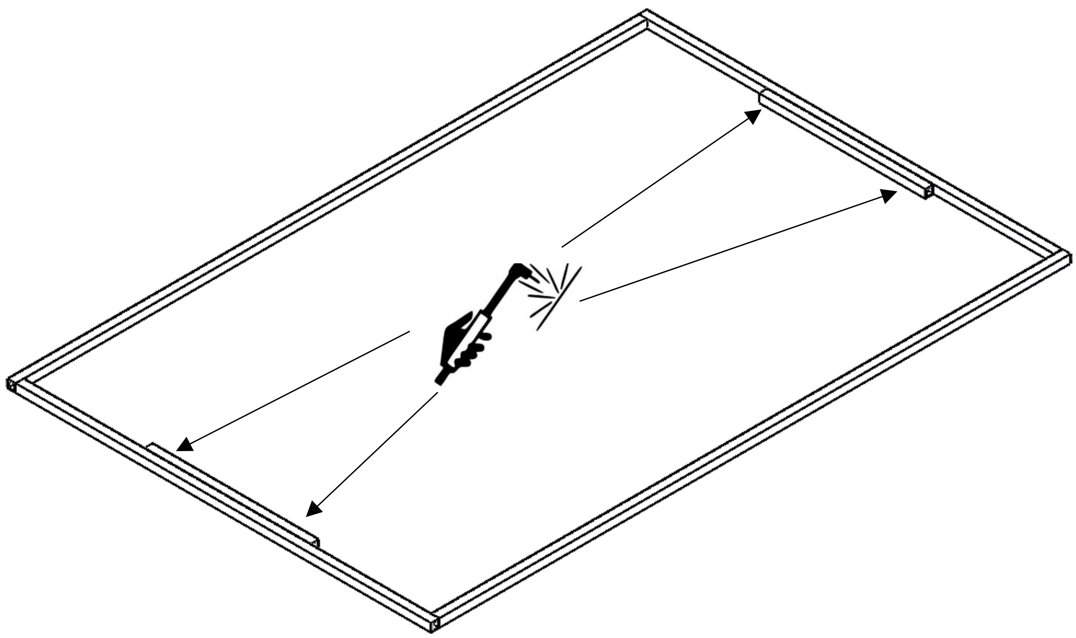
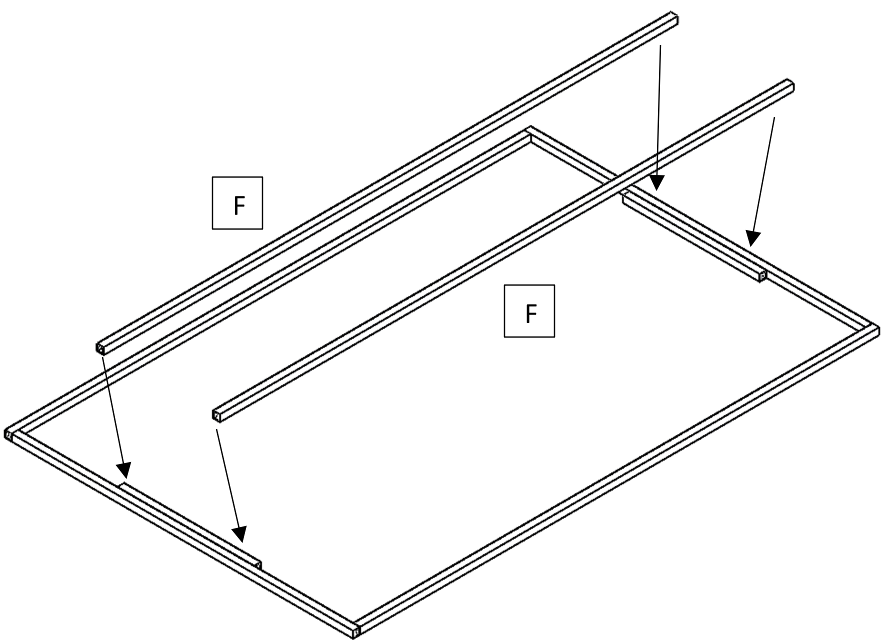
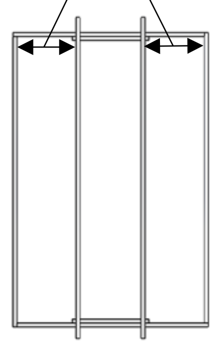




4)

F x2





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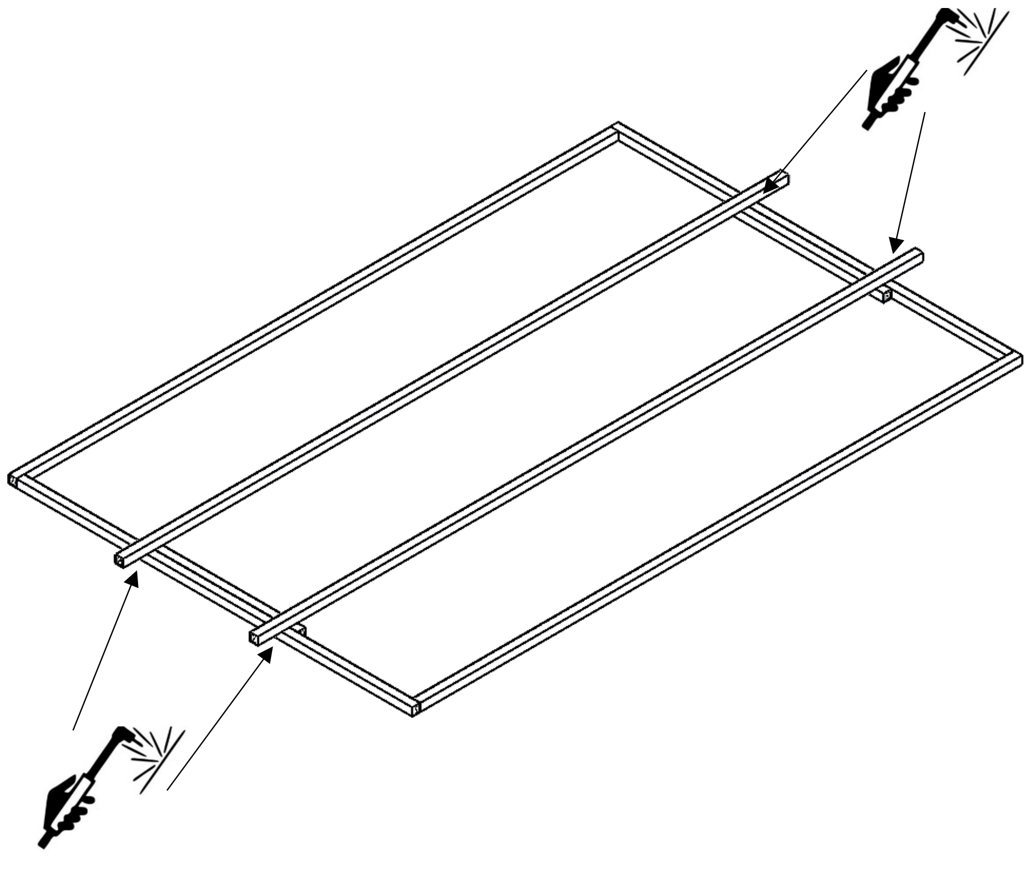

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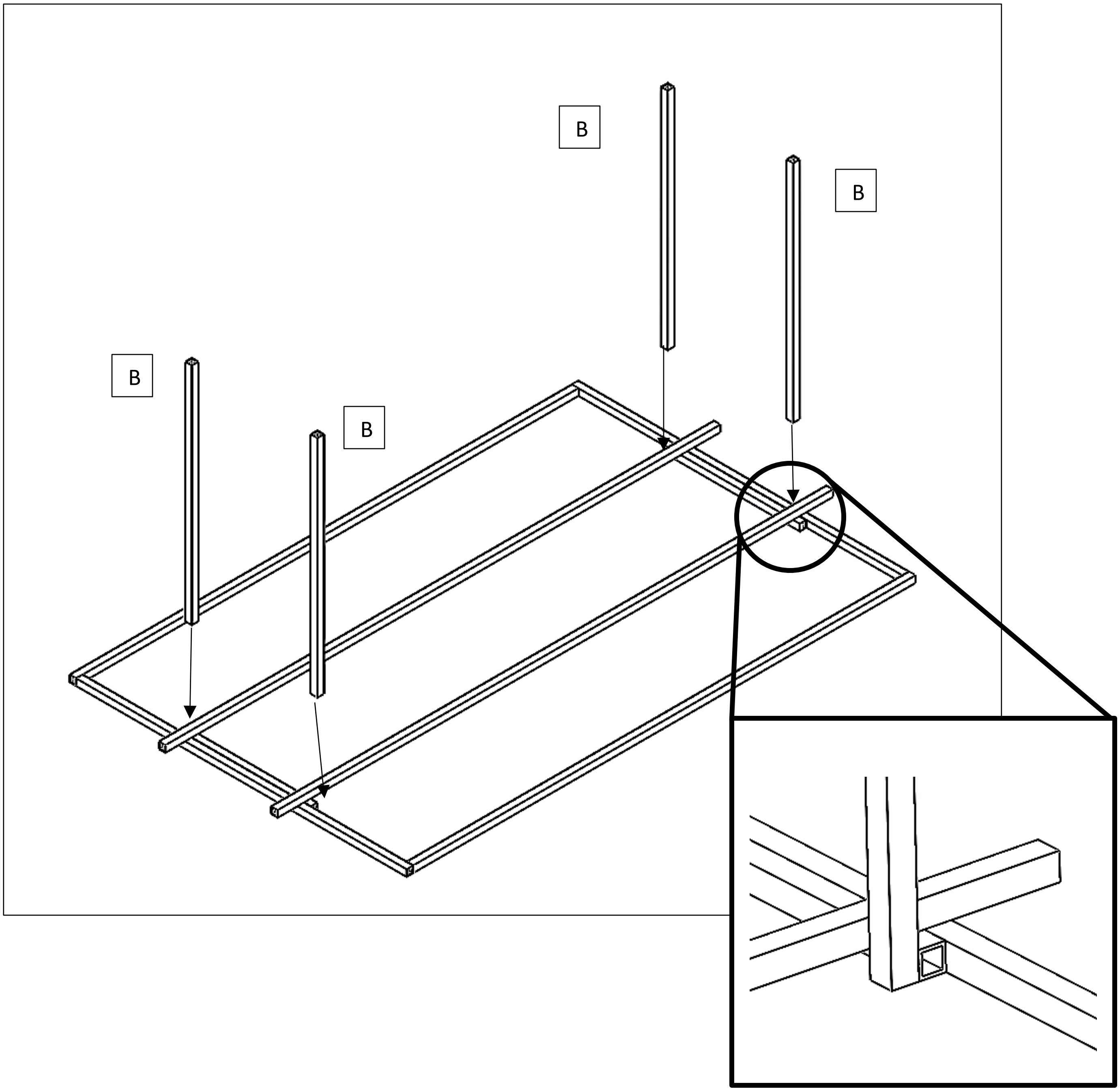

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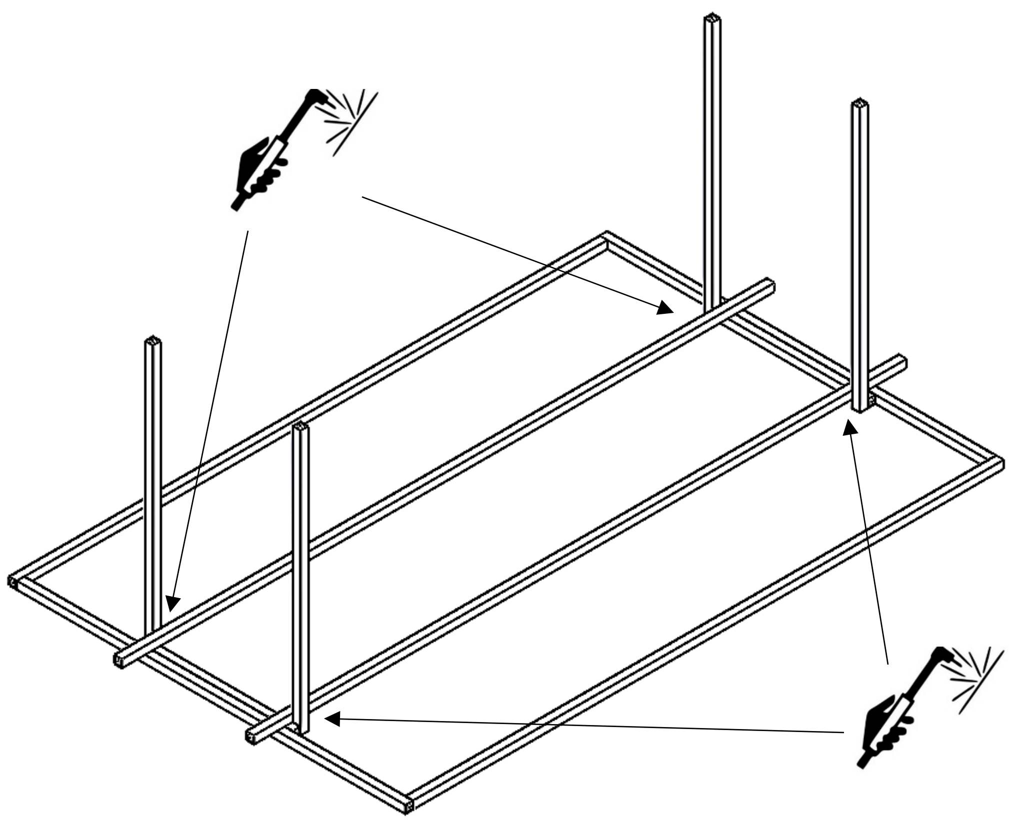

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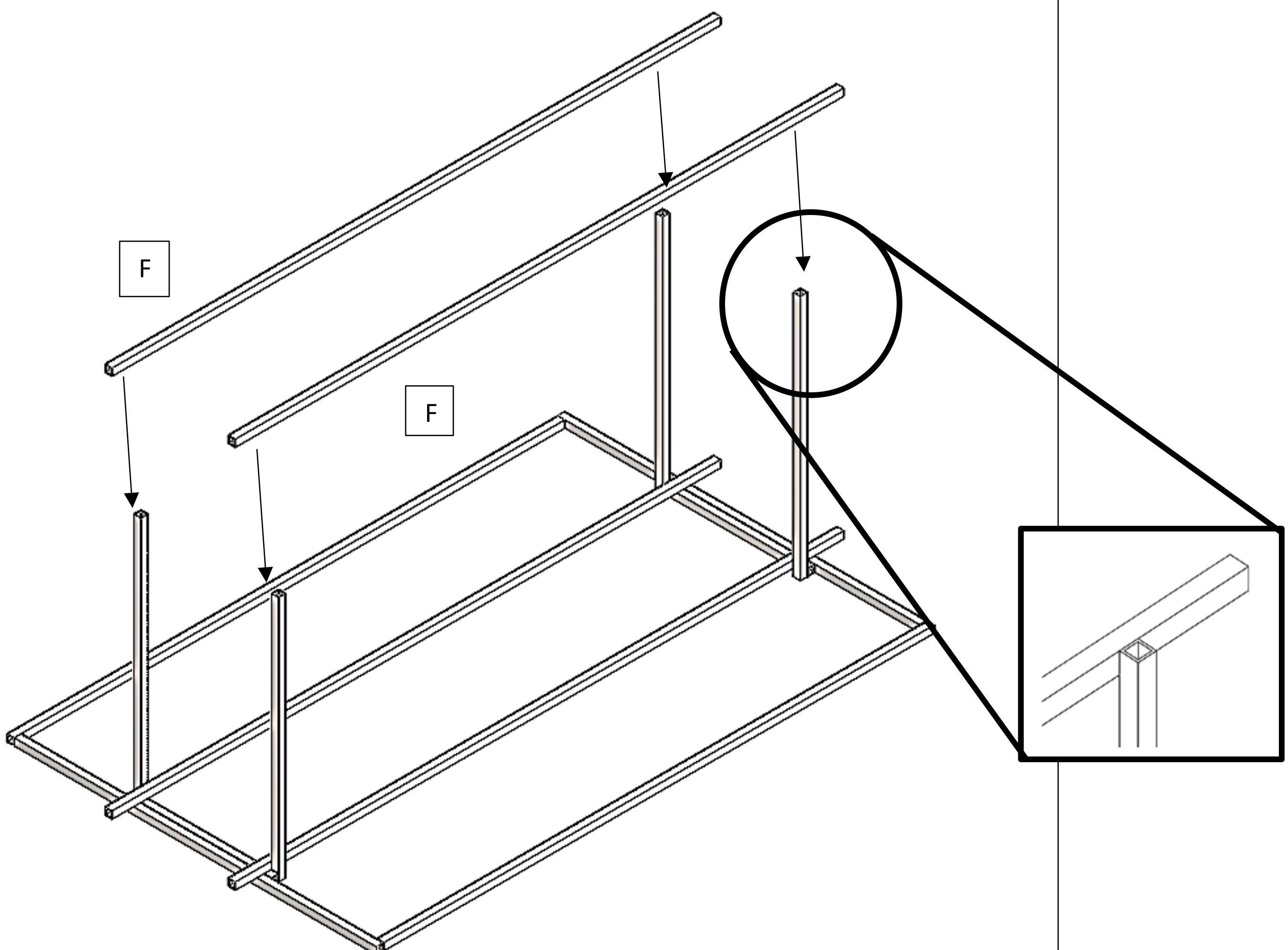

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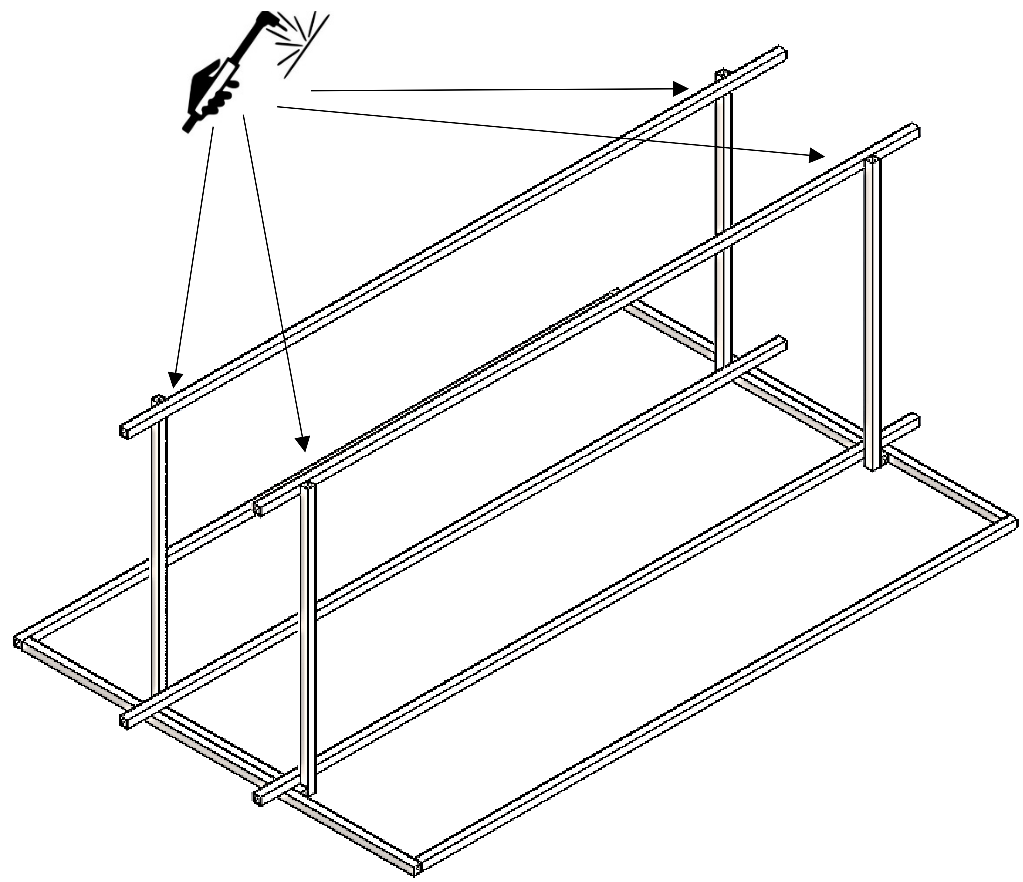
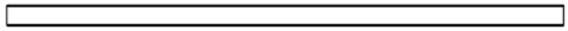
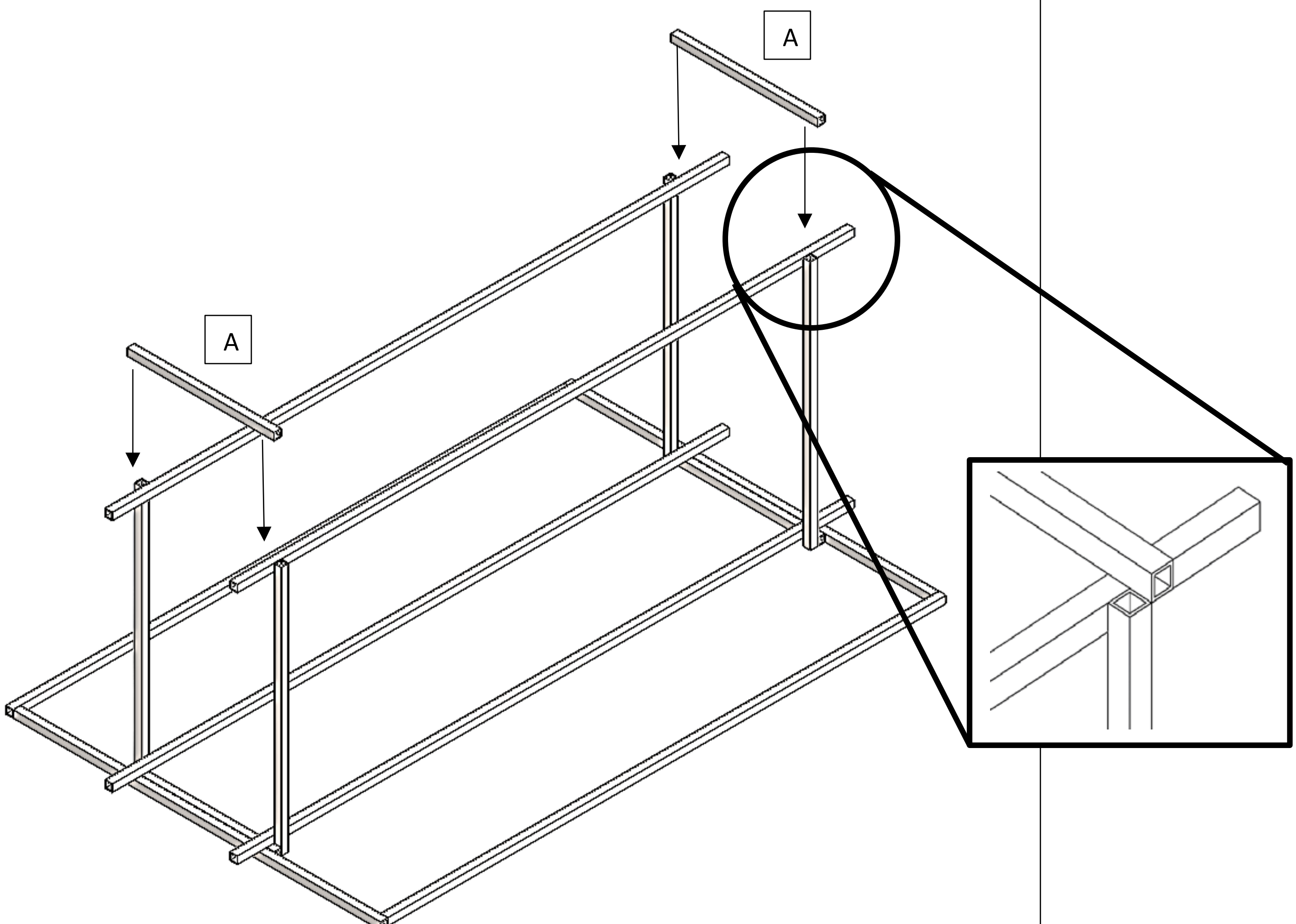


10)	A  x2	



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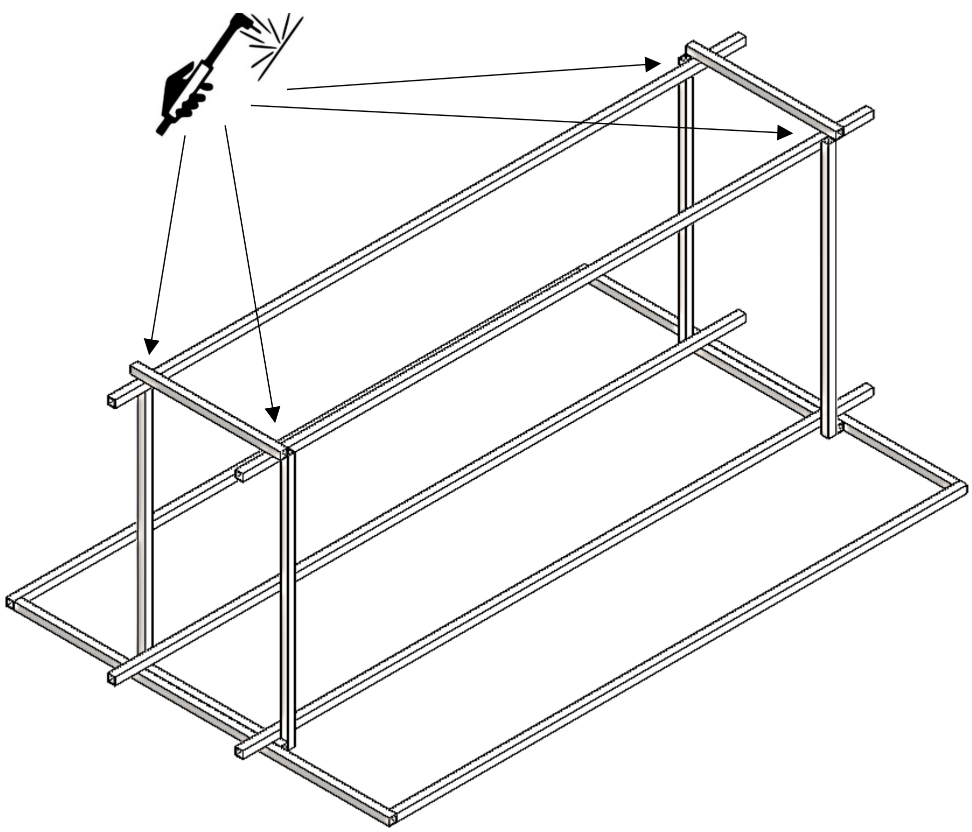
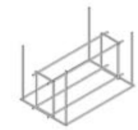
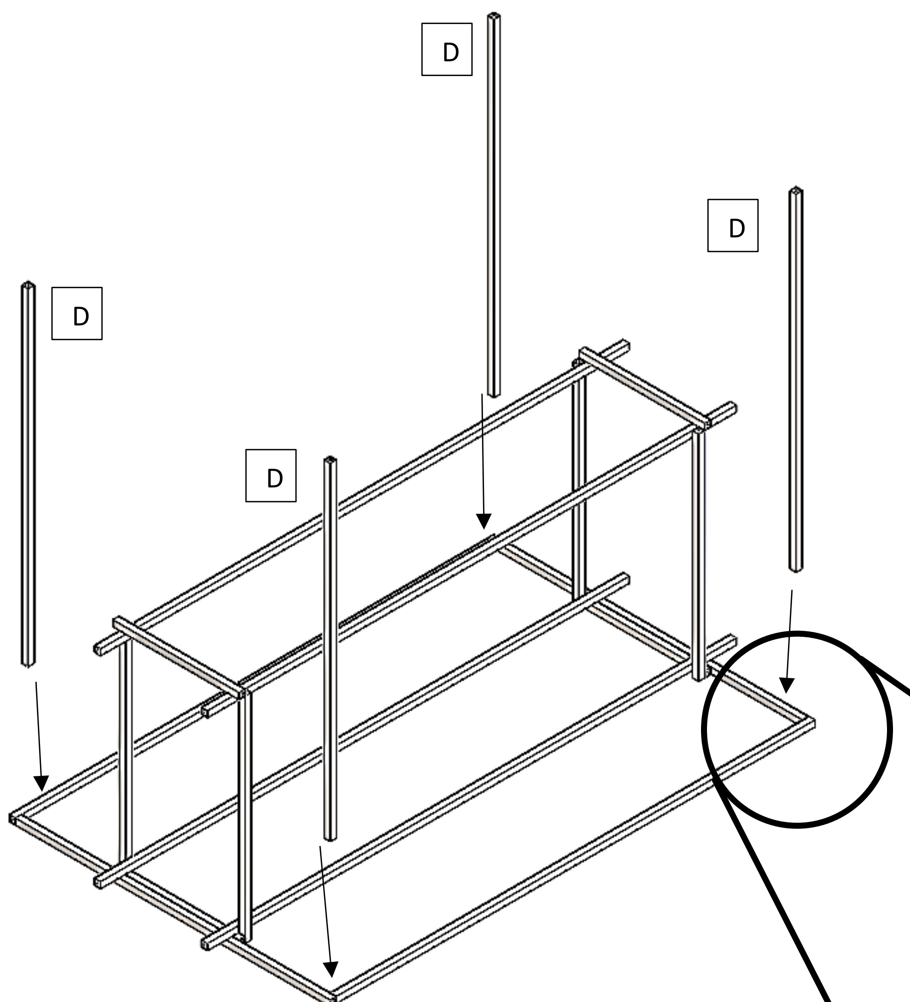
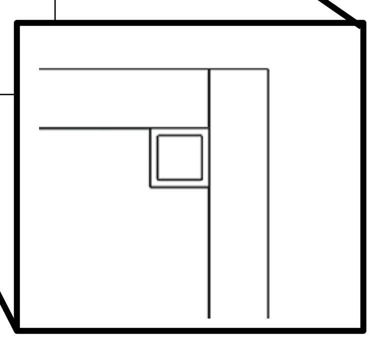
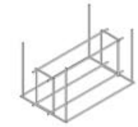
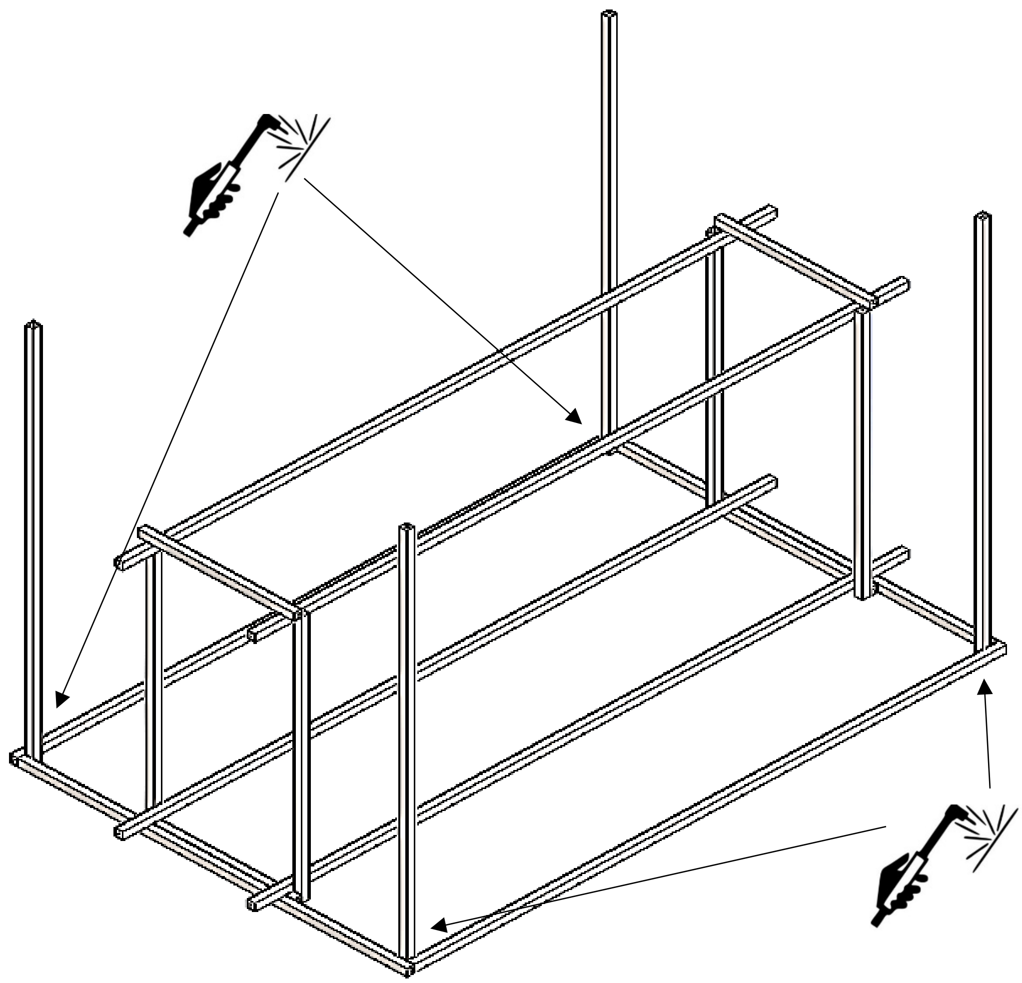


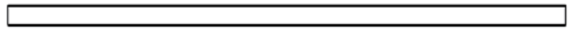
12)	D	x4	

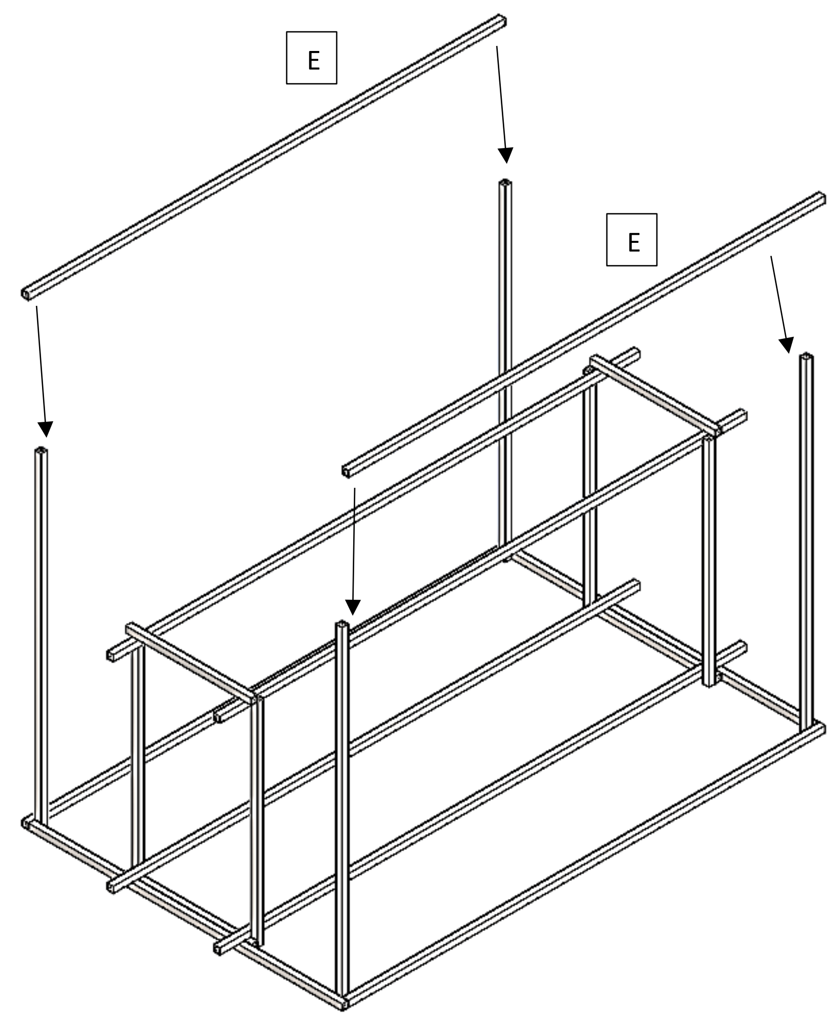


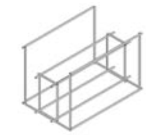


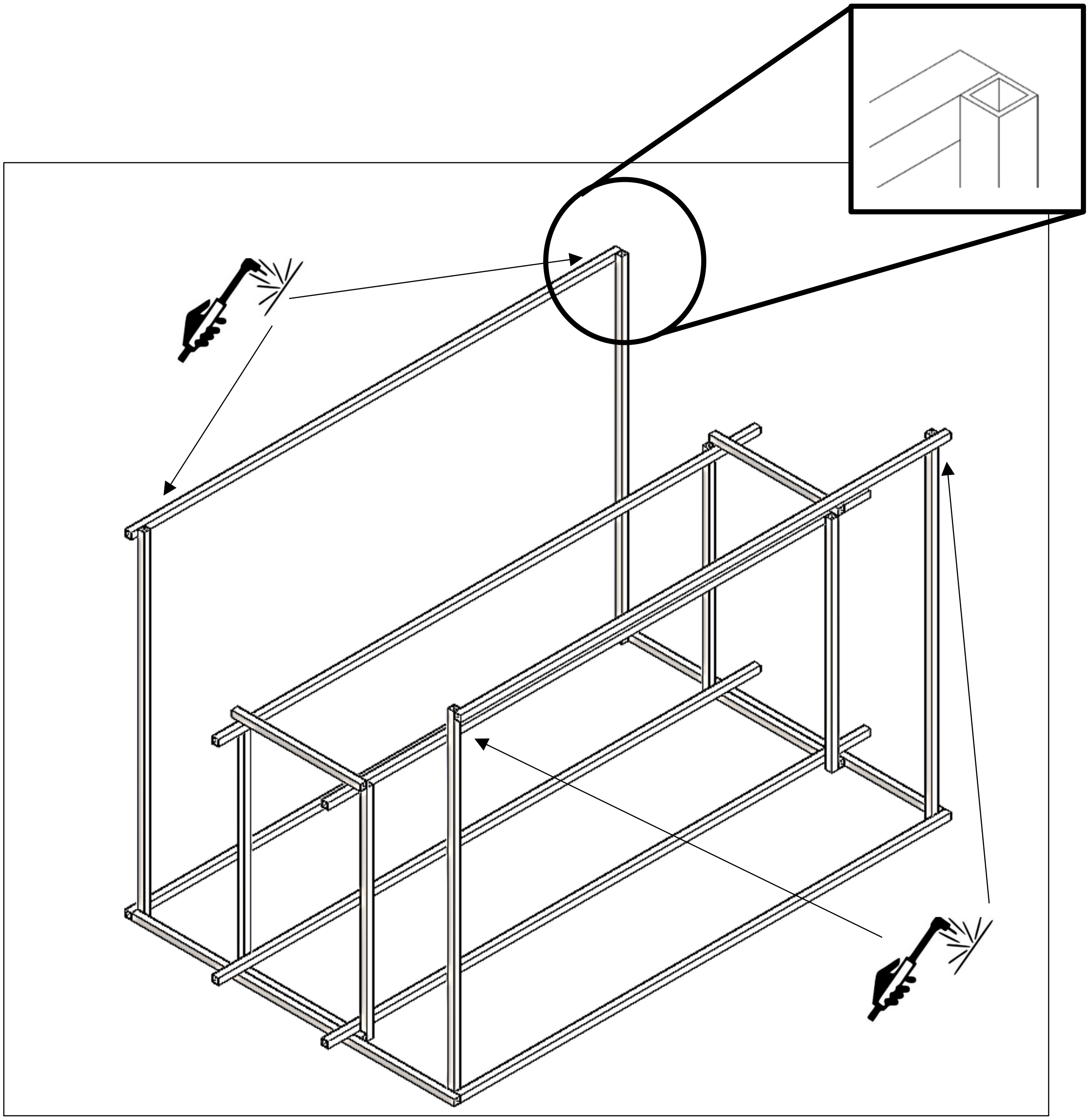
13)		

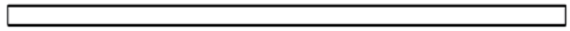
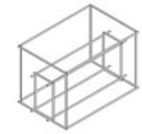


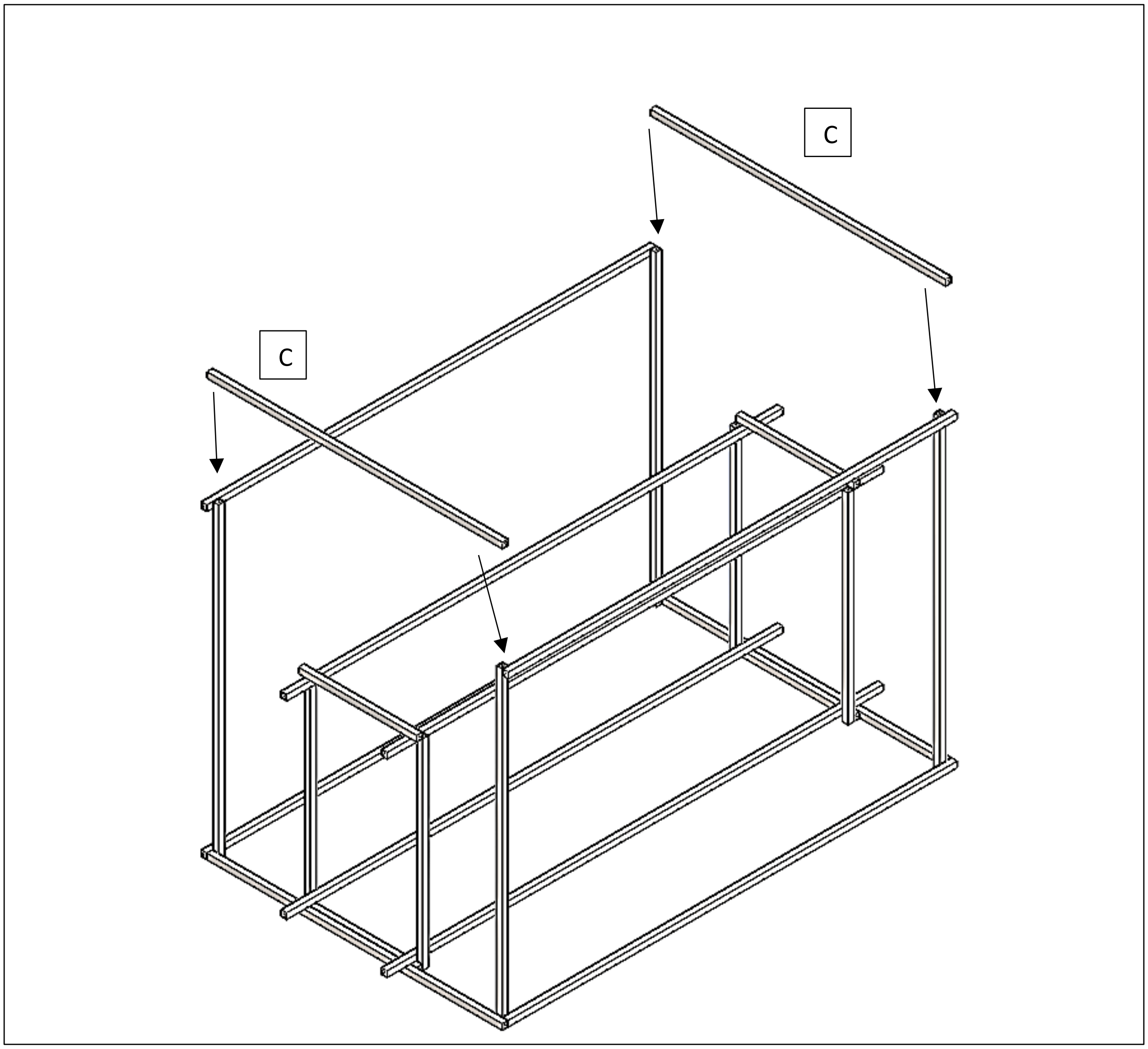
14)	E		x2	



15)		



16)	C		x2	



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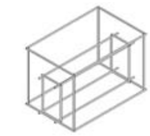

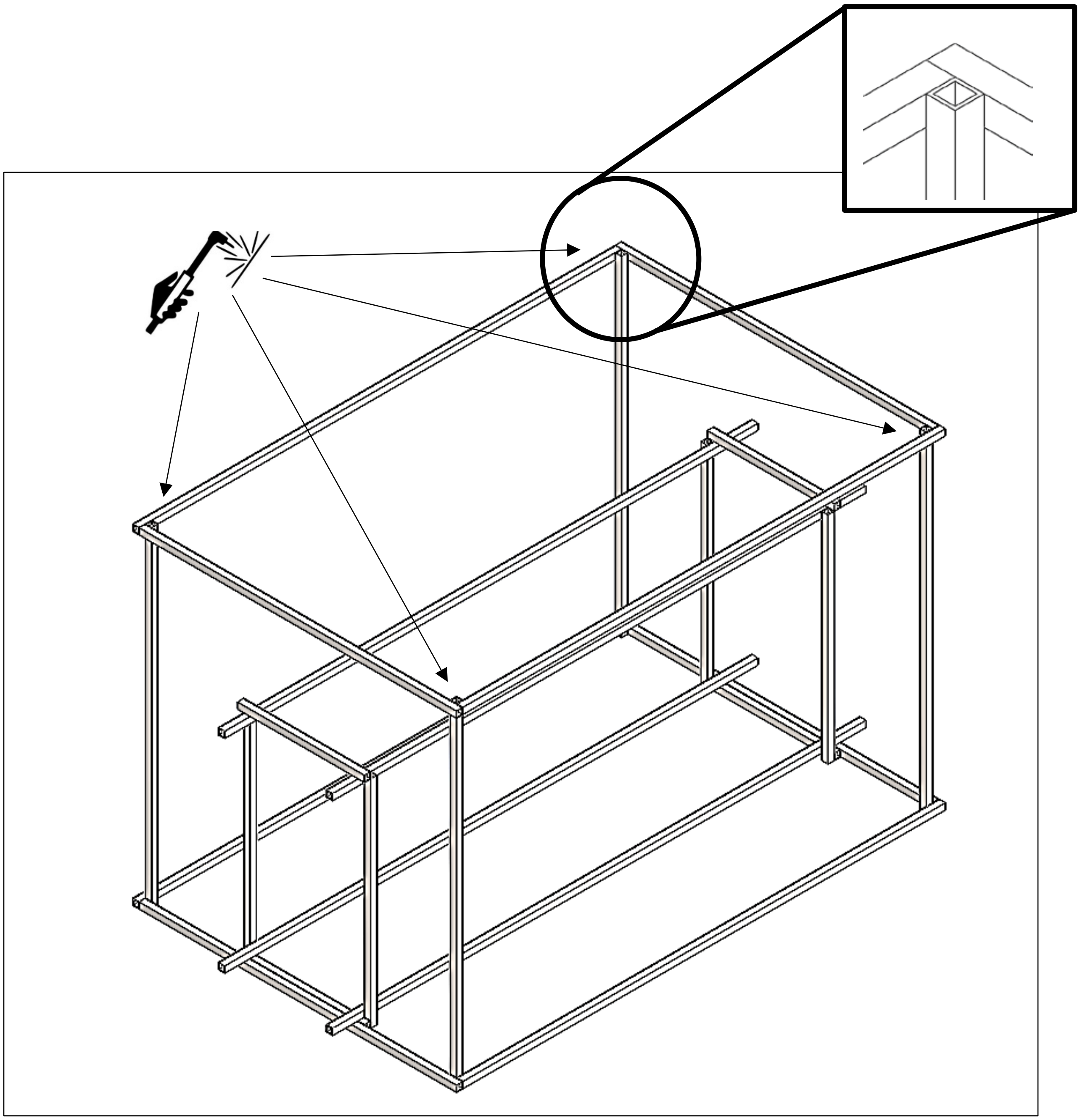

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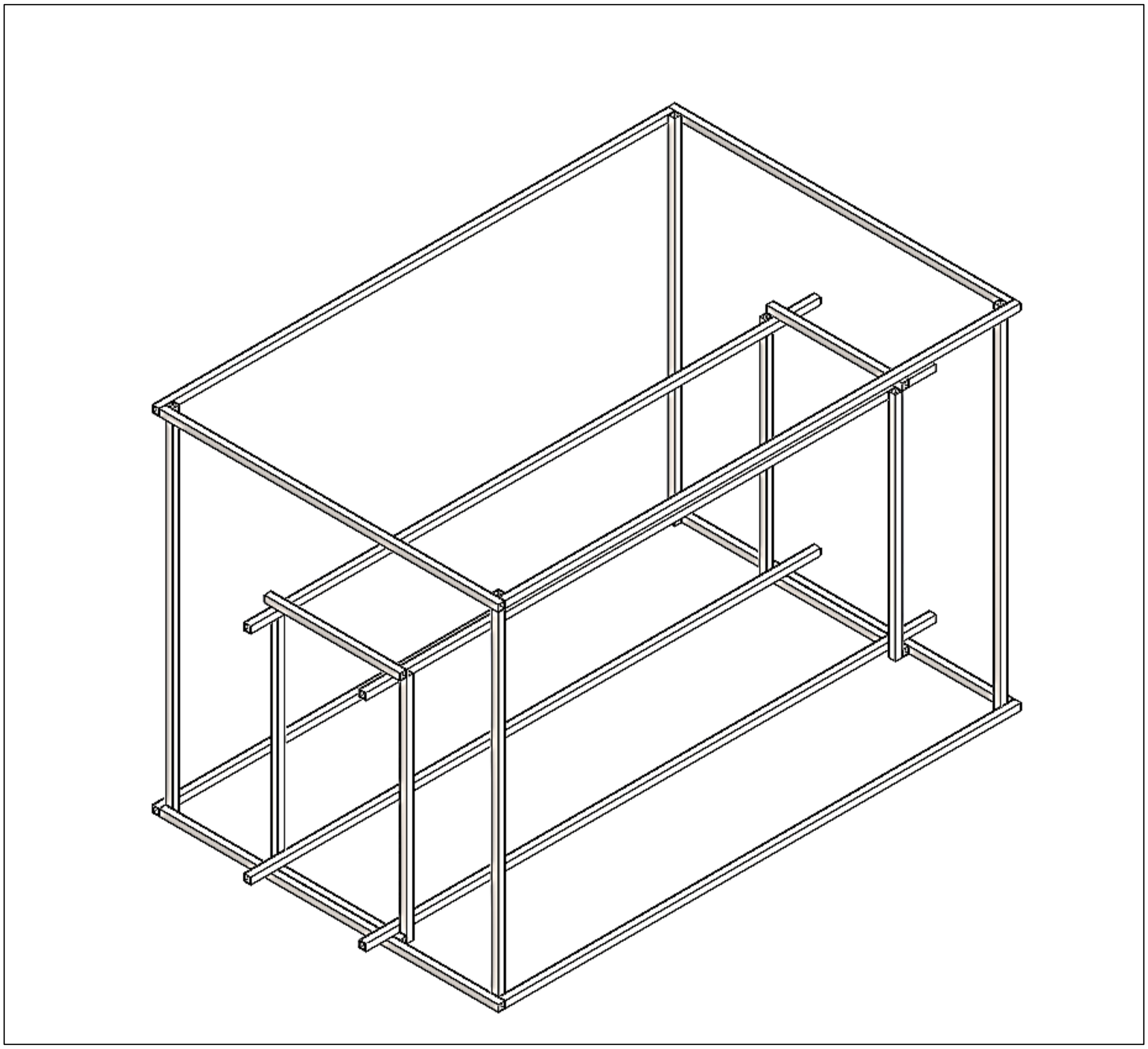
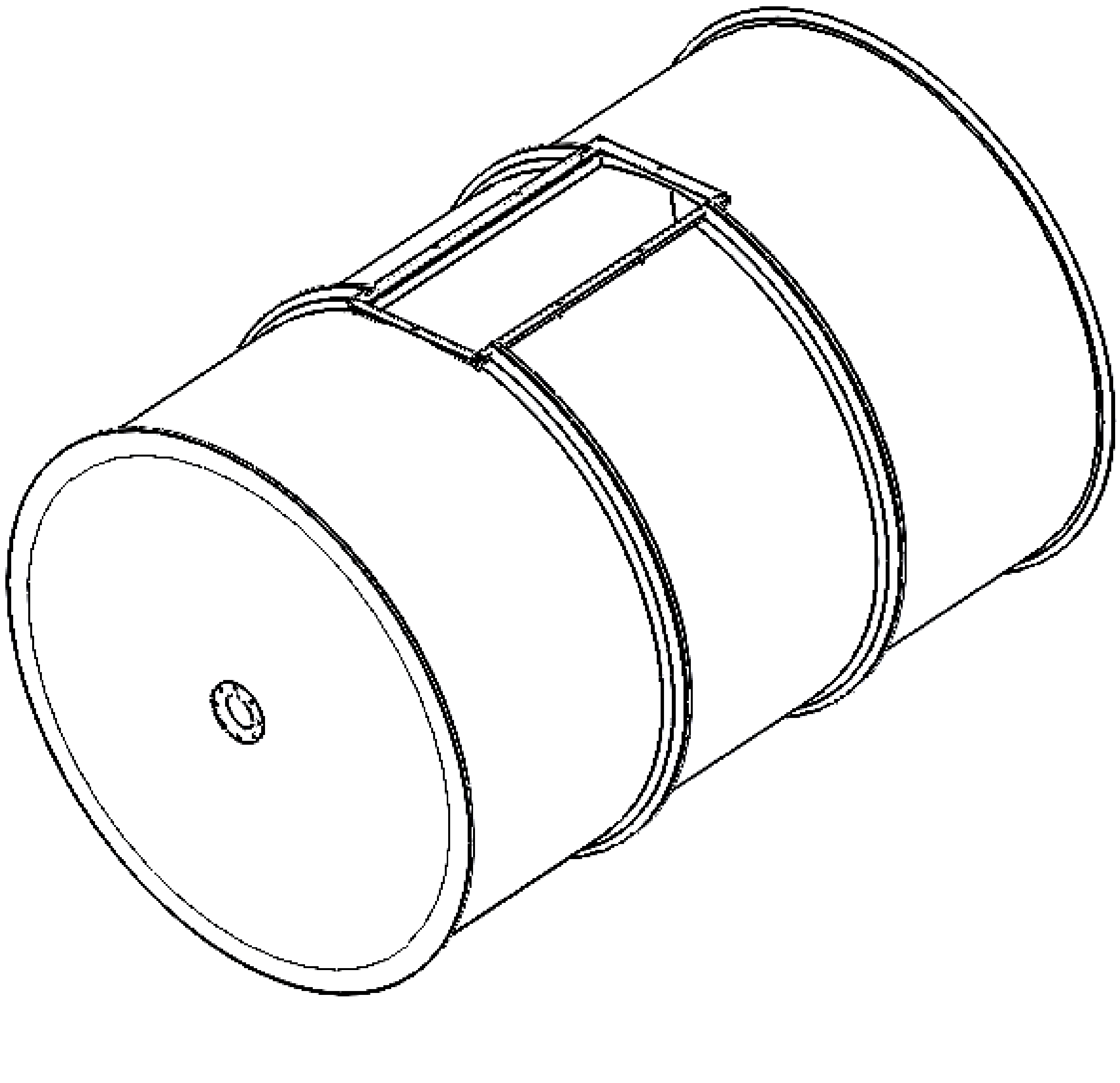


Drum:



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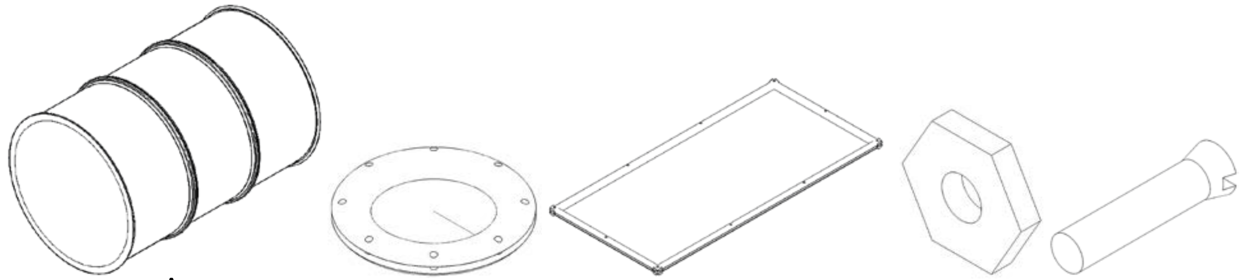
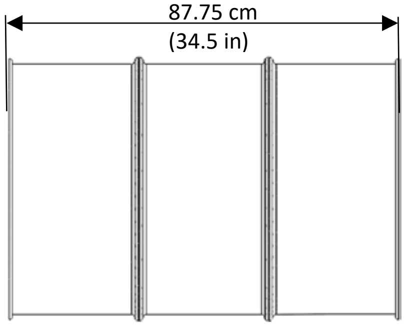
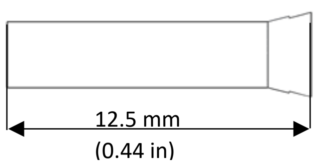


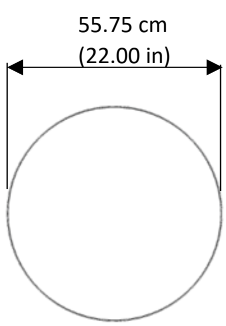
A B C D E



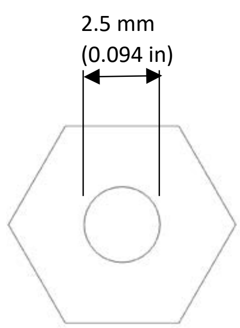
A



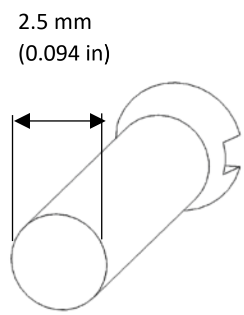
E



A



D



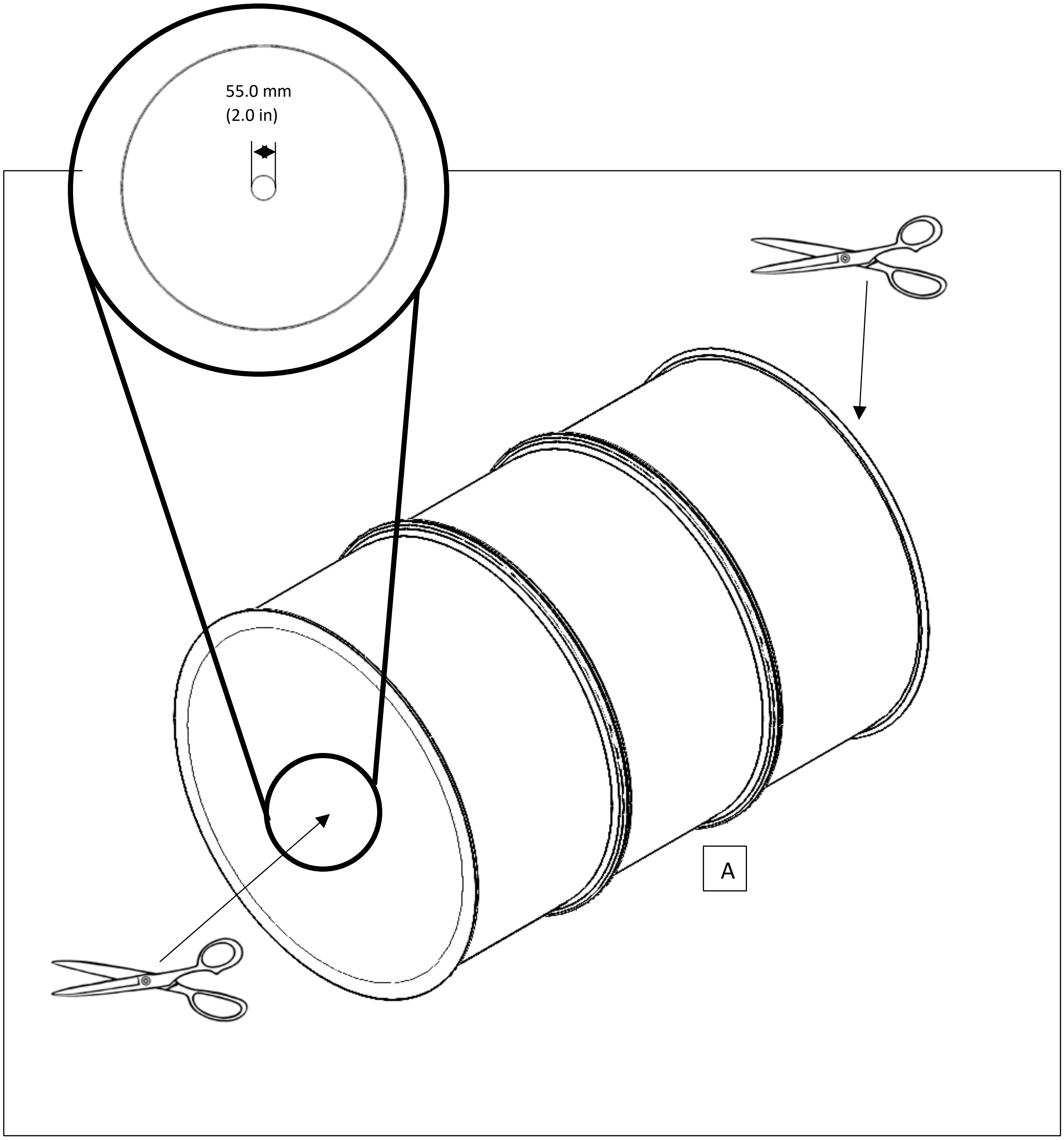
E

A	x1
B	x2
C	x1
D	x26
E	x26

1)

A

x1



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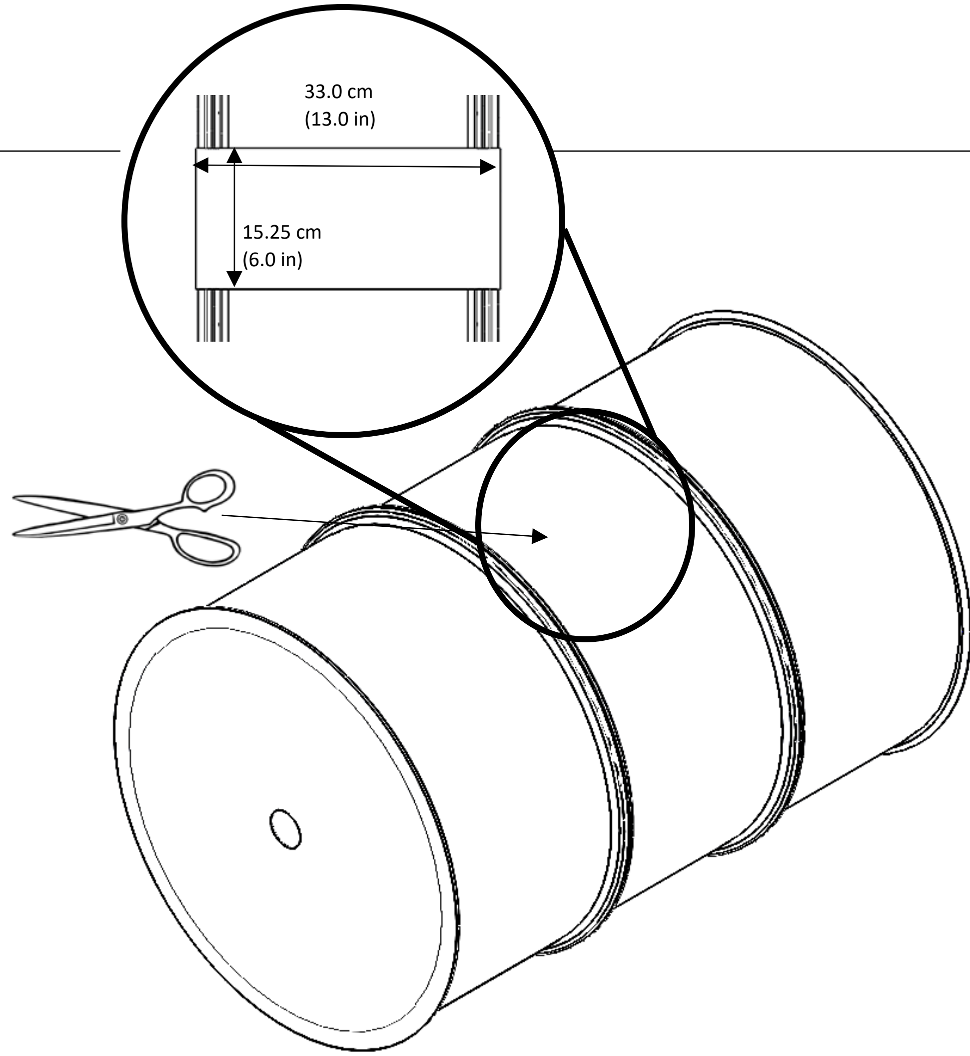

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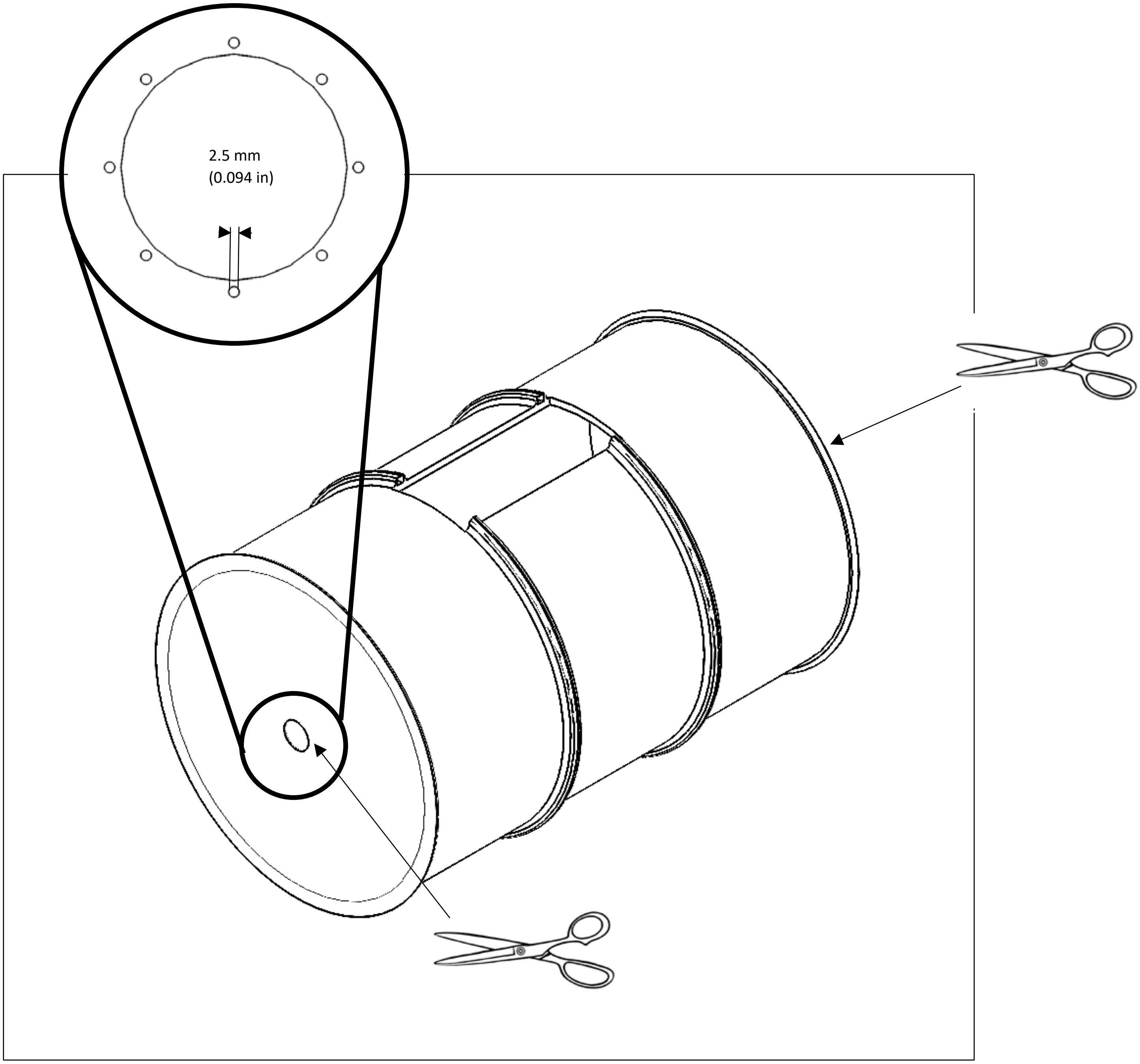

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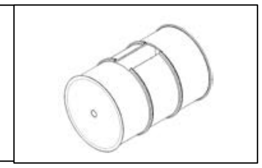
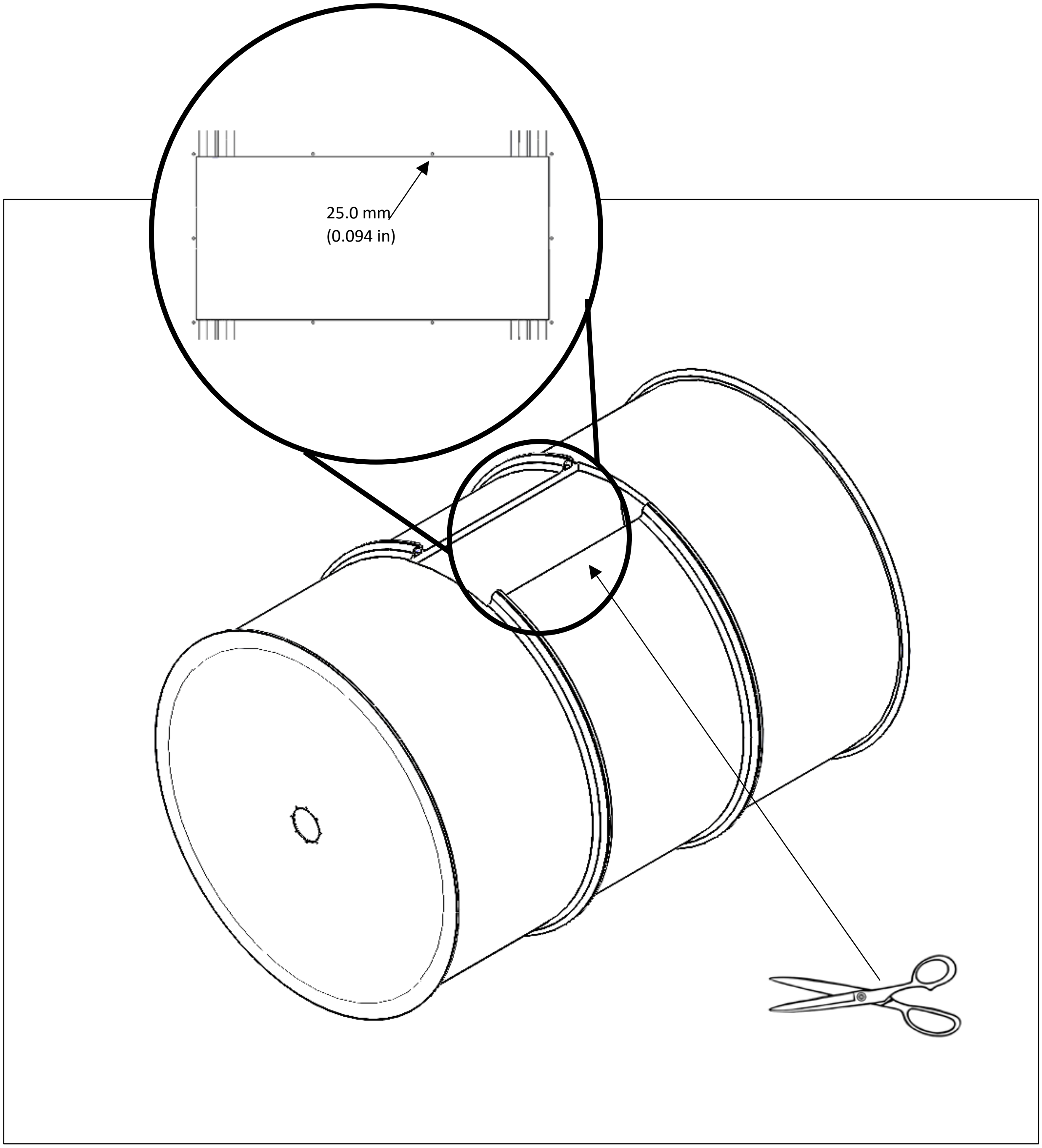
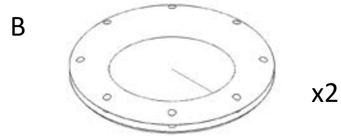
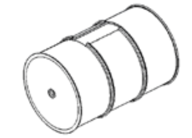
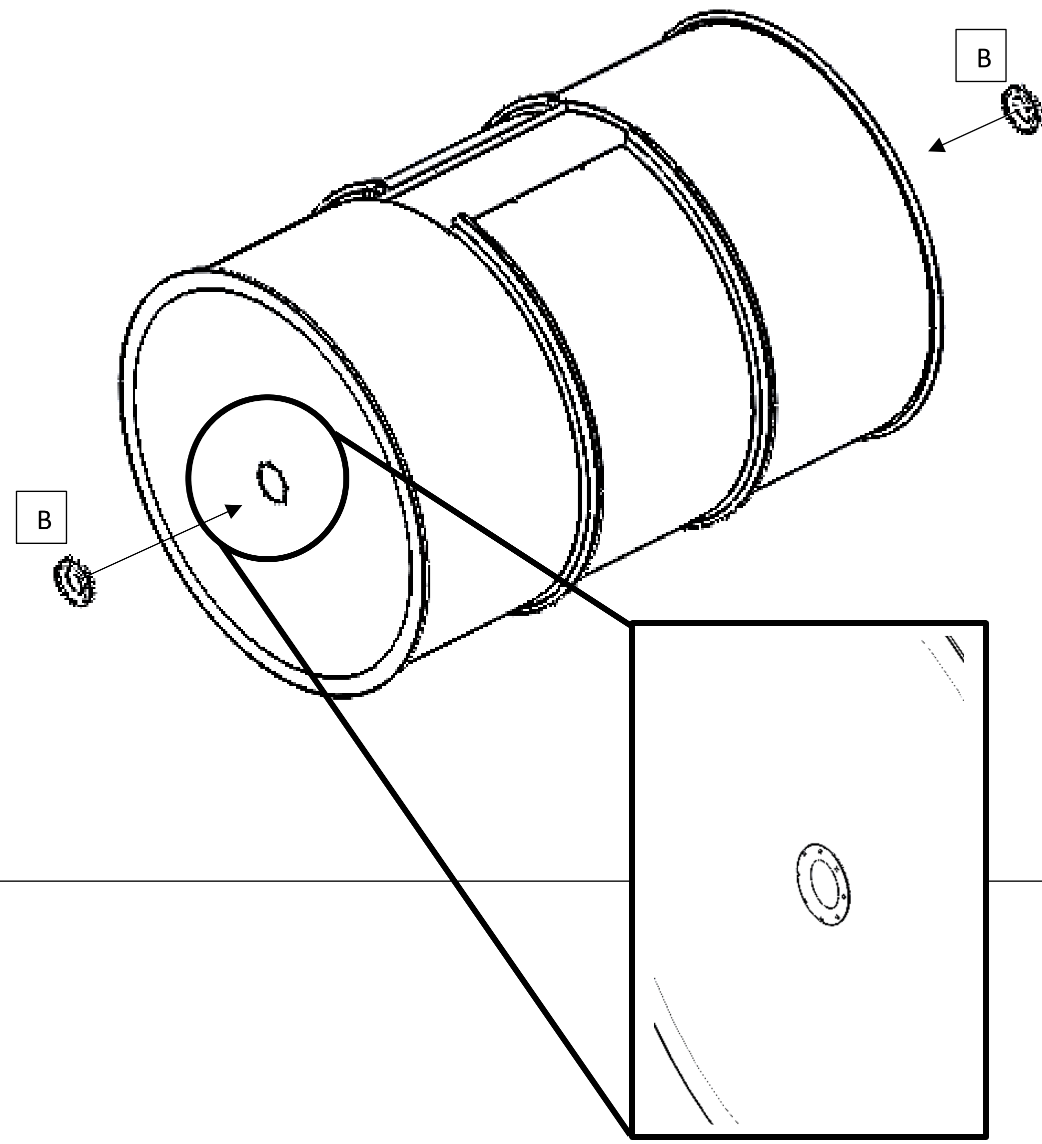
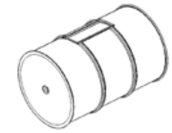
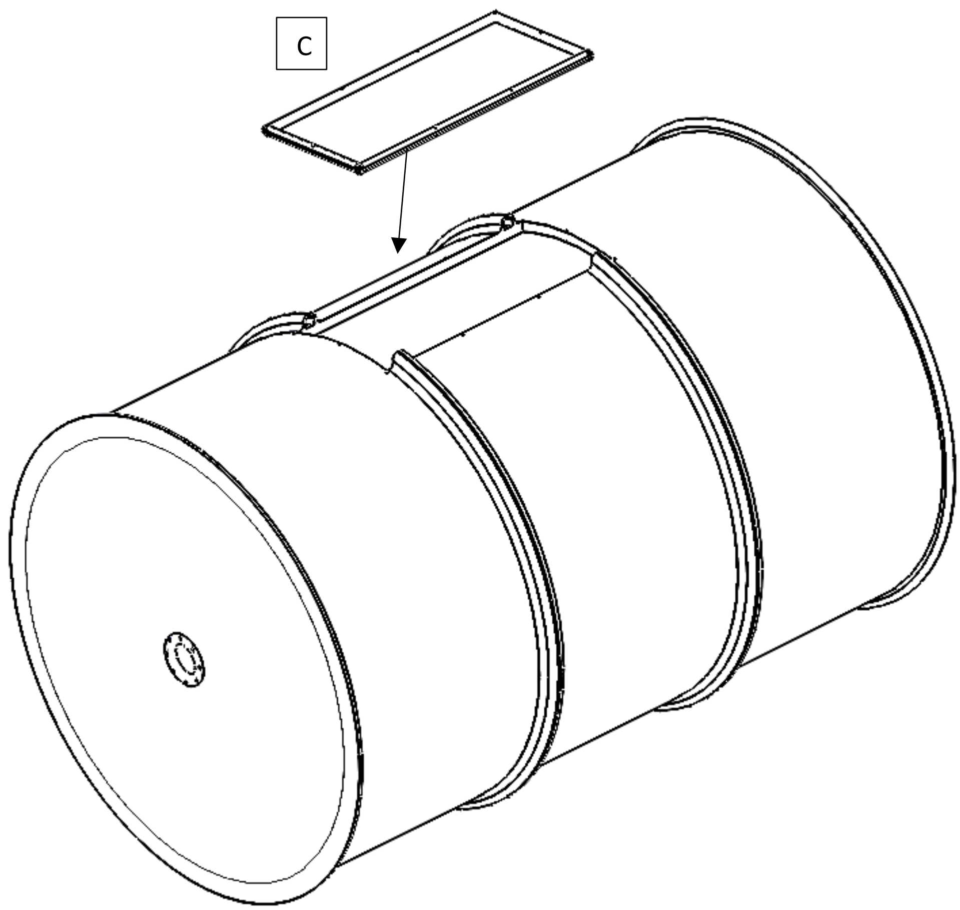


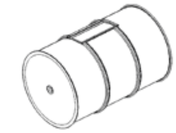


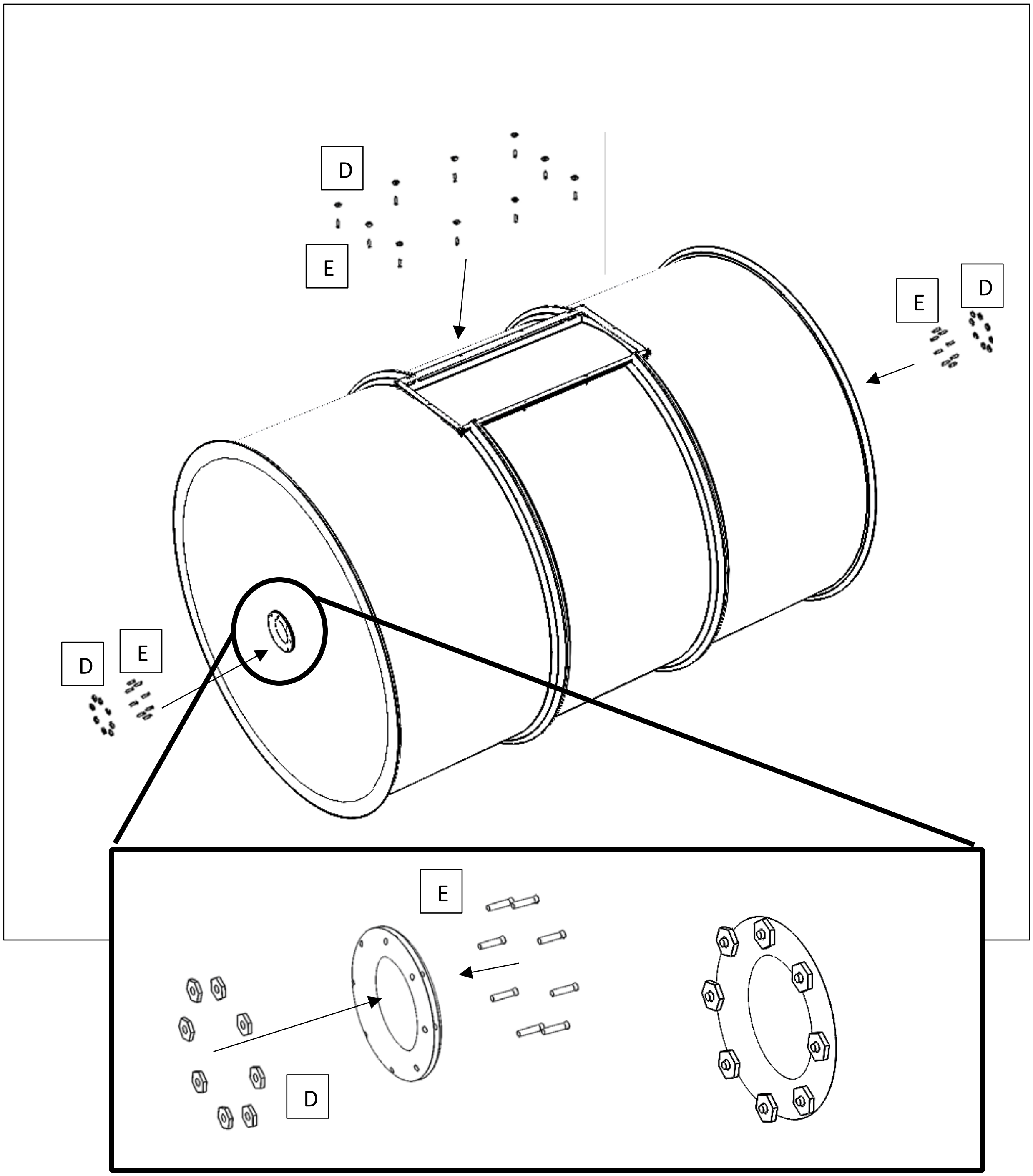
5)		

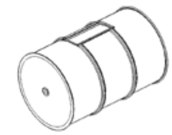


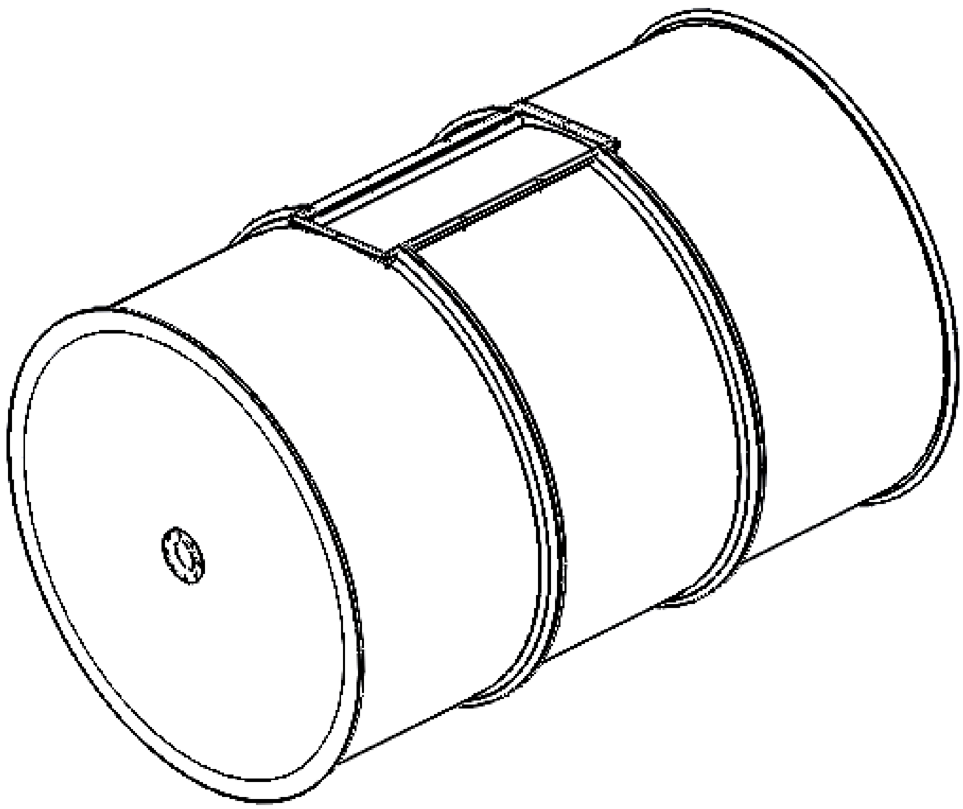
6)		



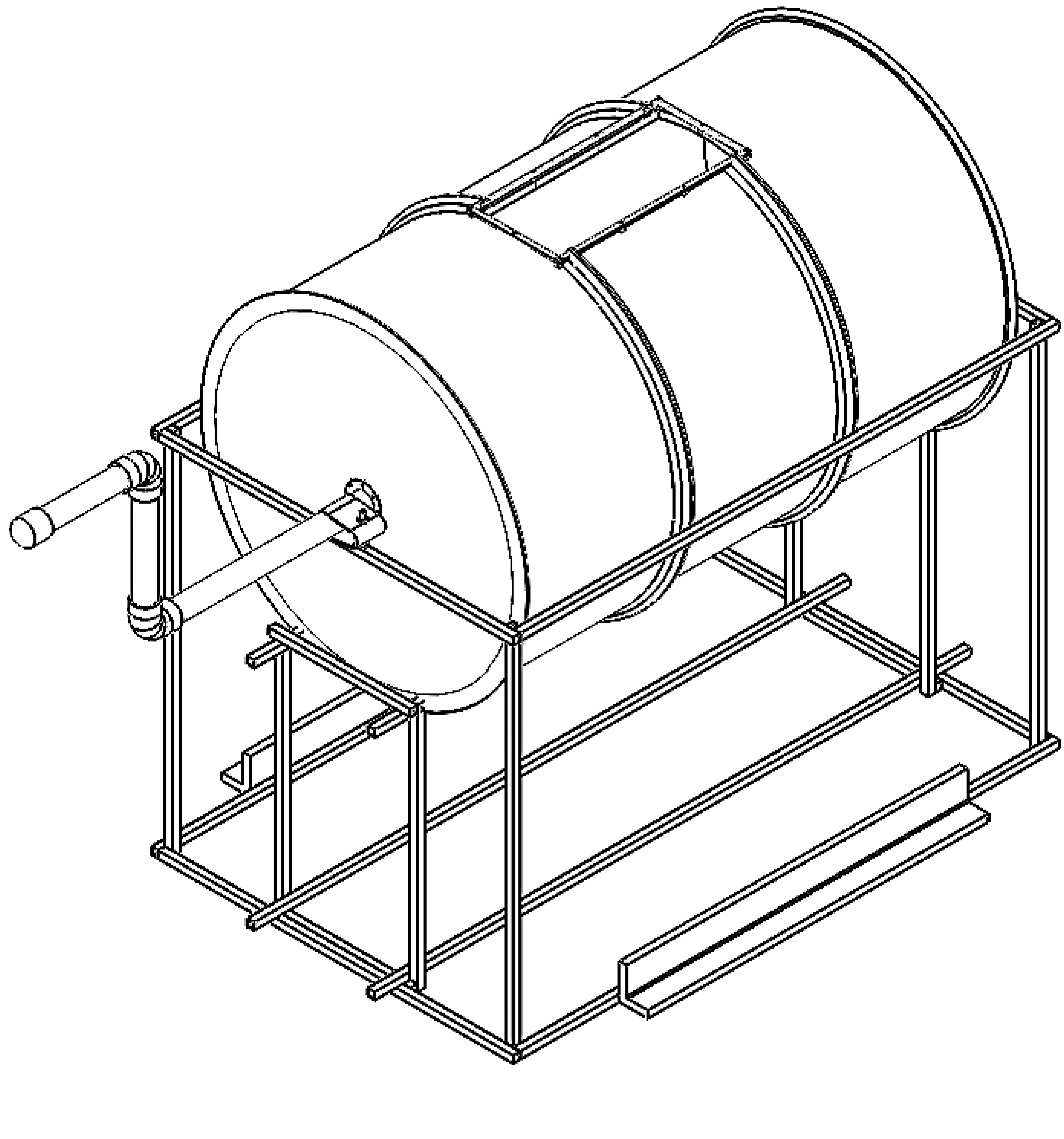
7)		



8)		



Assembly:



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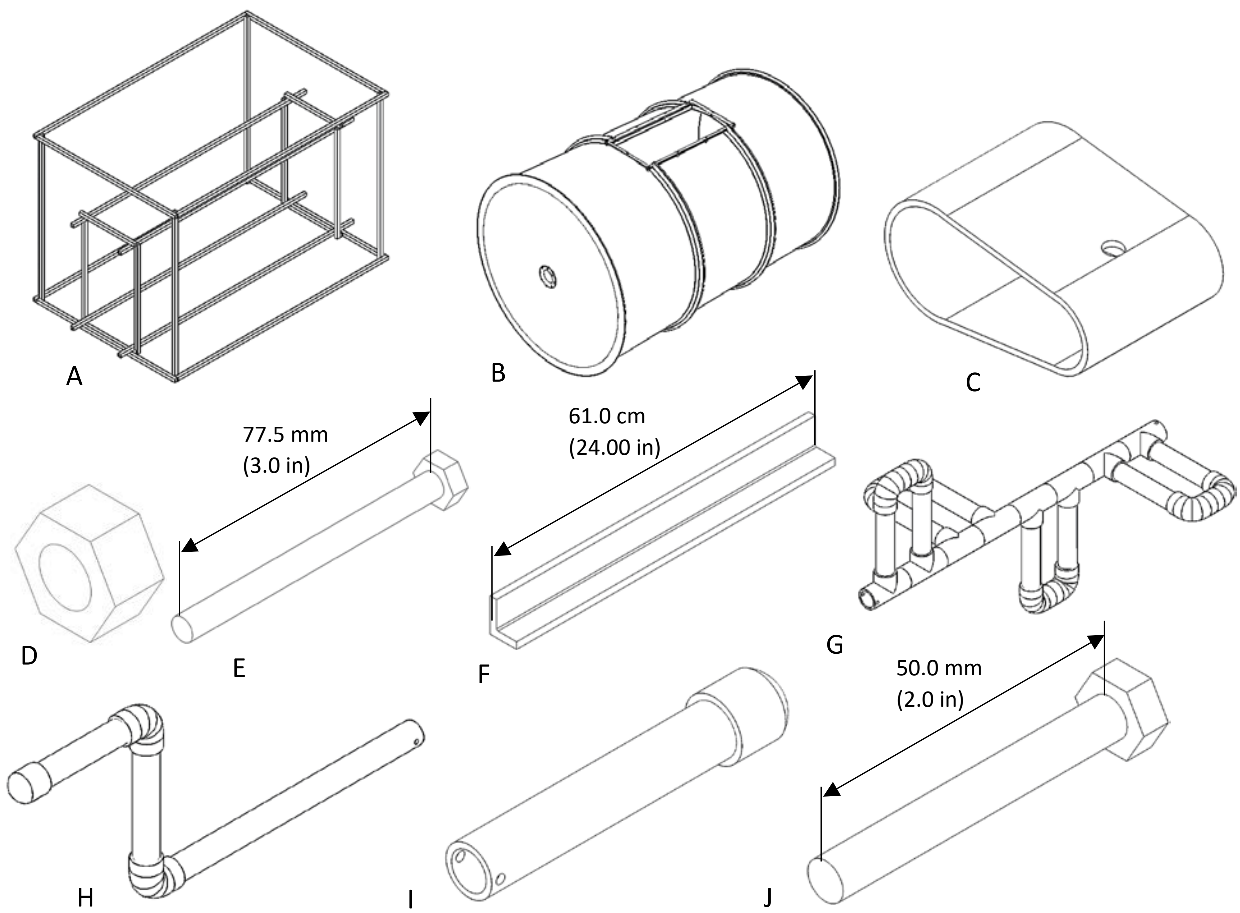
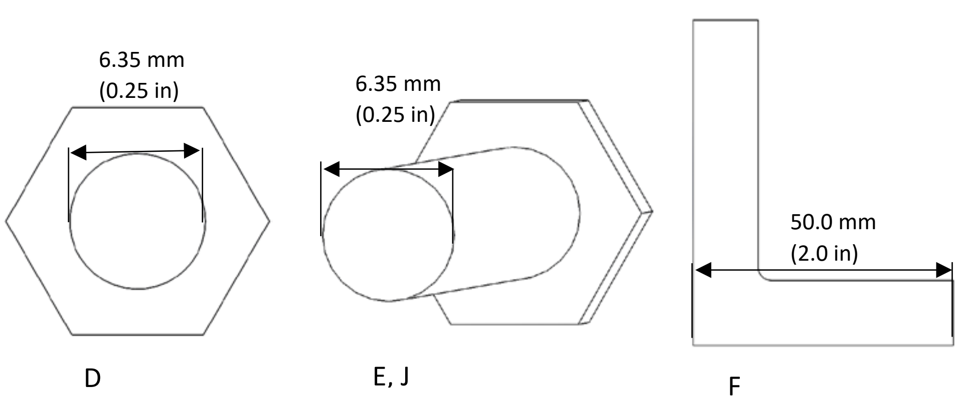
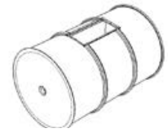
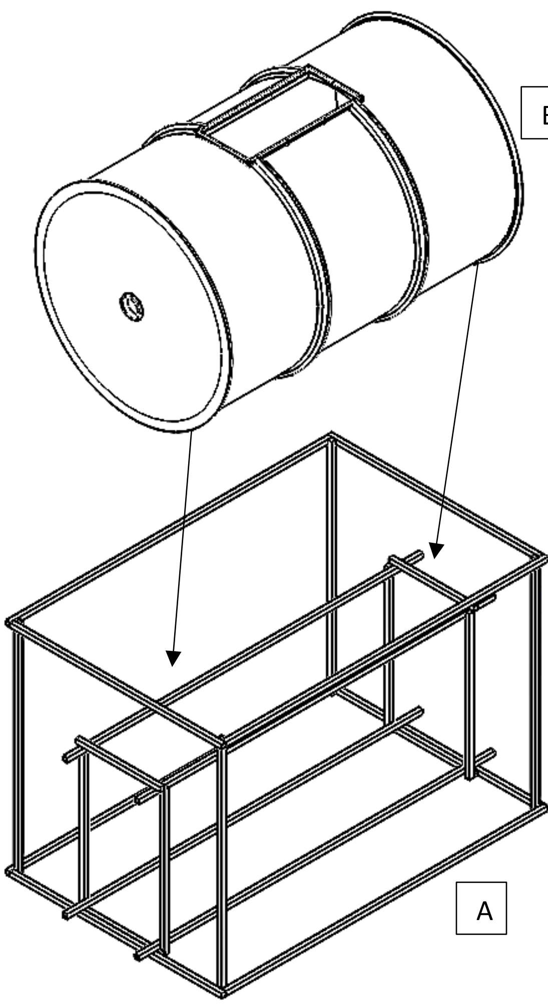


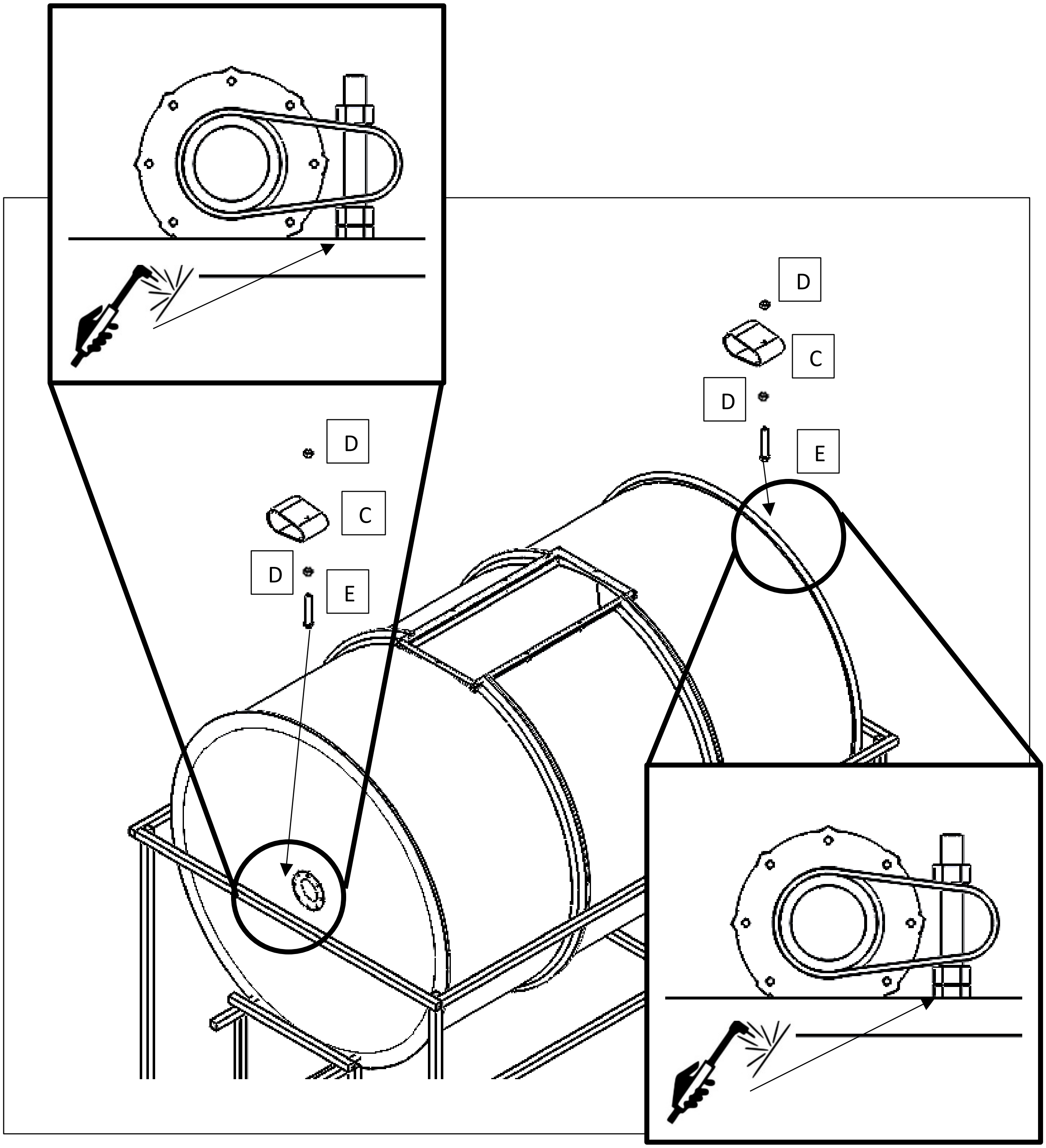


A	x1
B	x1
C	x2
D	x8
E	x2
F	x2
G	x1
H	x1
I	x1
J	x2

1)	A  x1 B  x1	



2)	C  x2 D  x4 E  x2	



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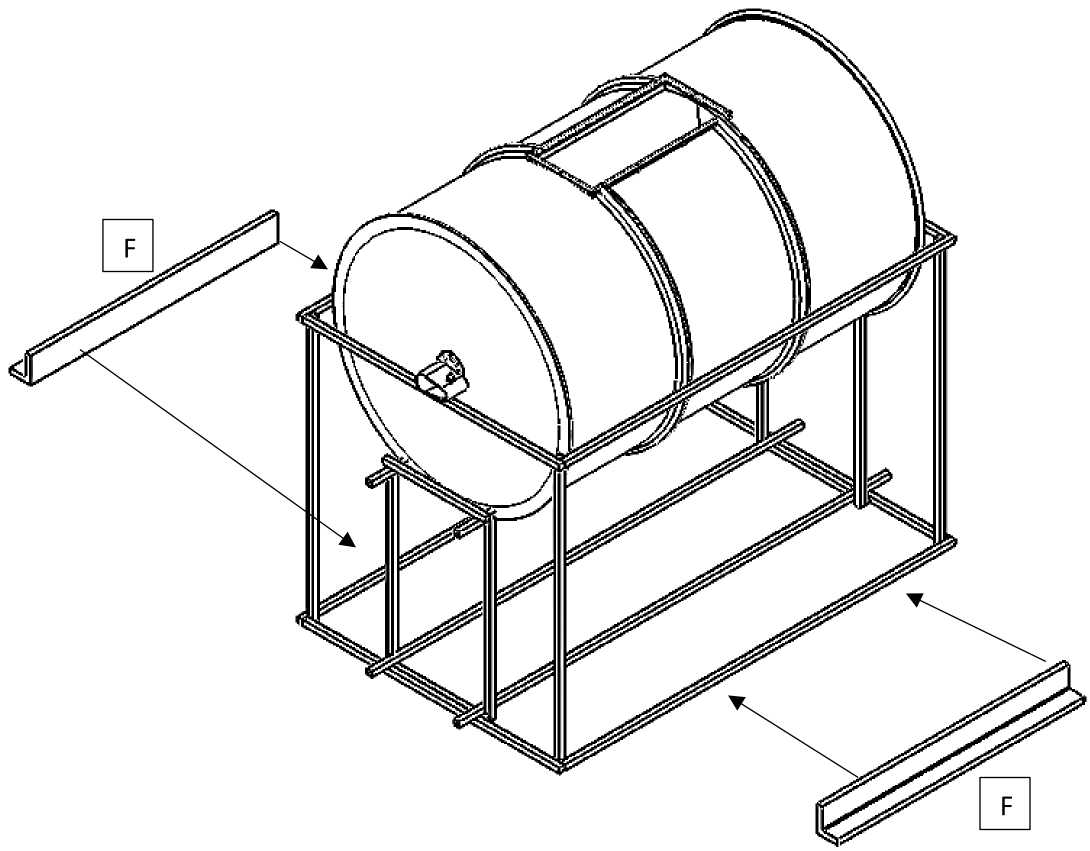
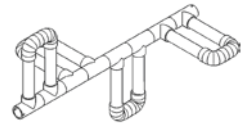
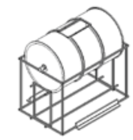
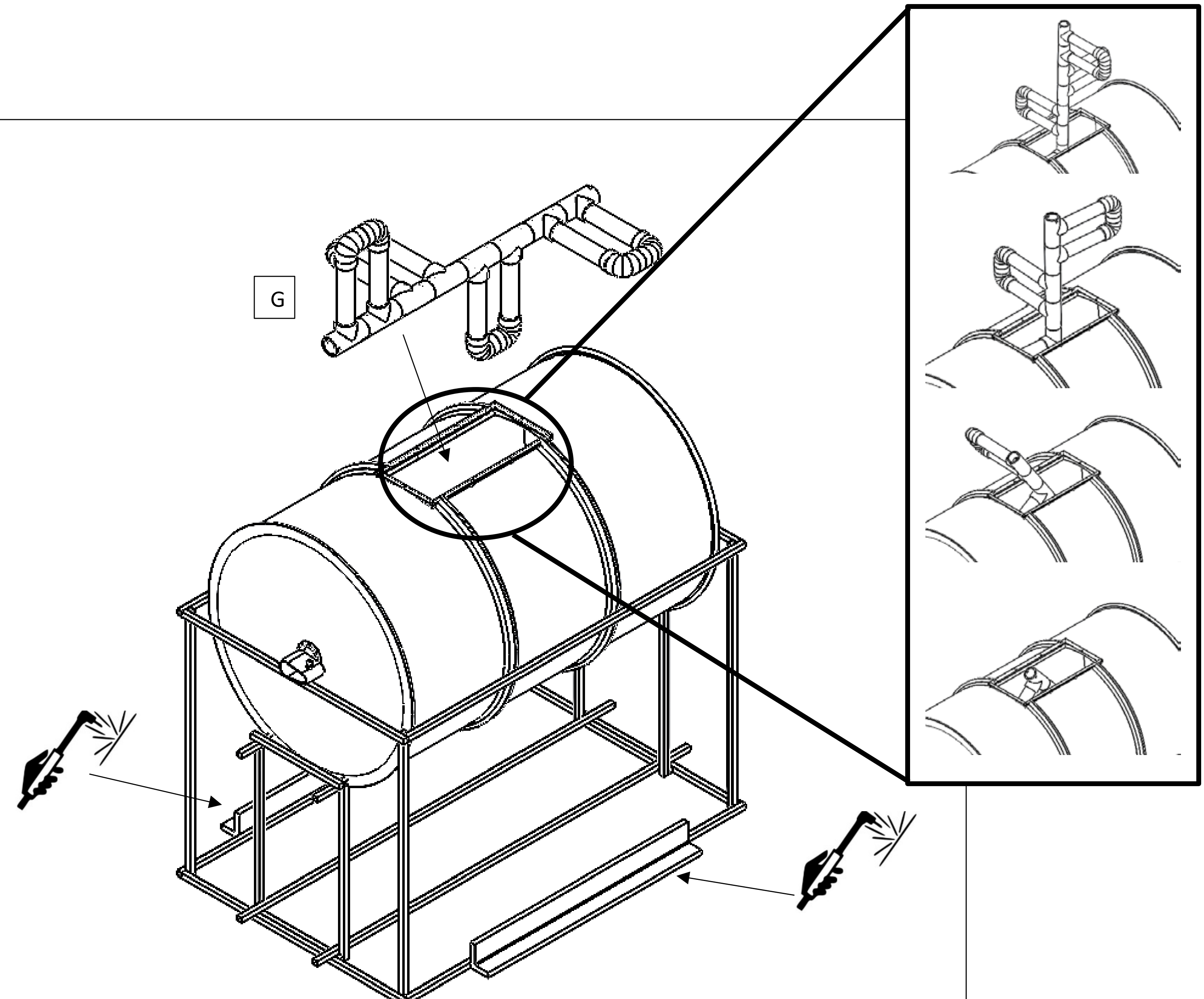
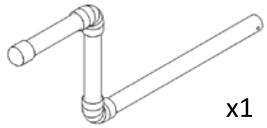
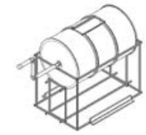
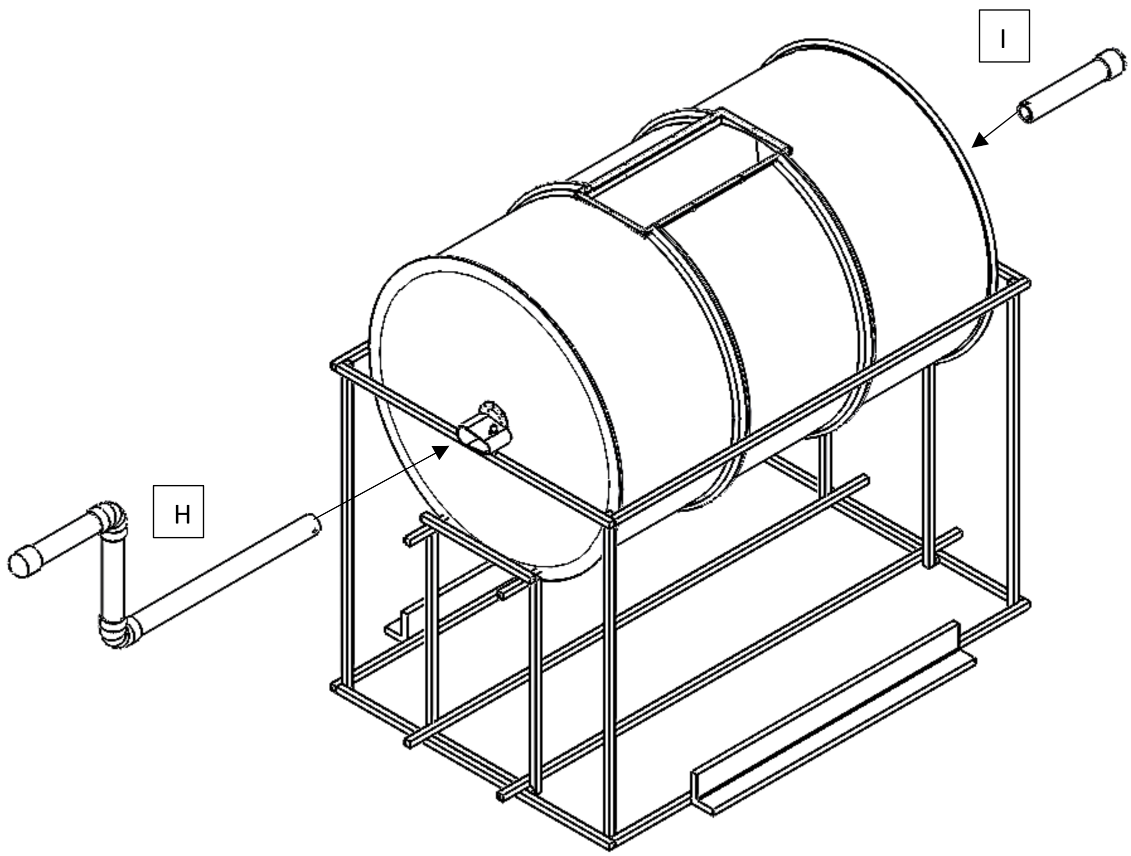


4)	G  x1	



5)	H  x1	I  x1	



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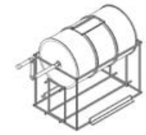
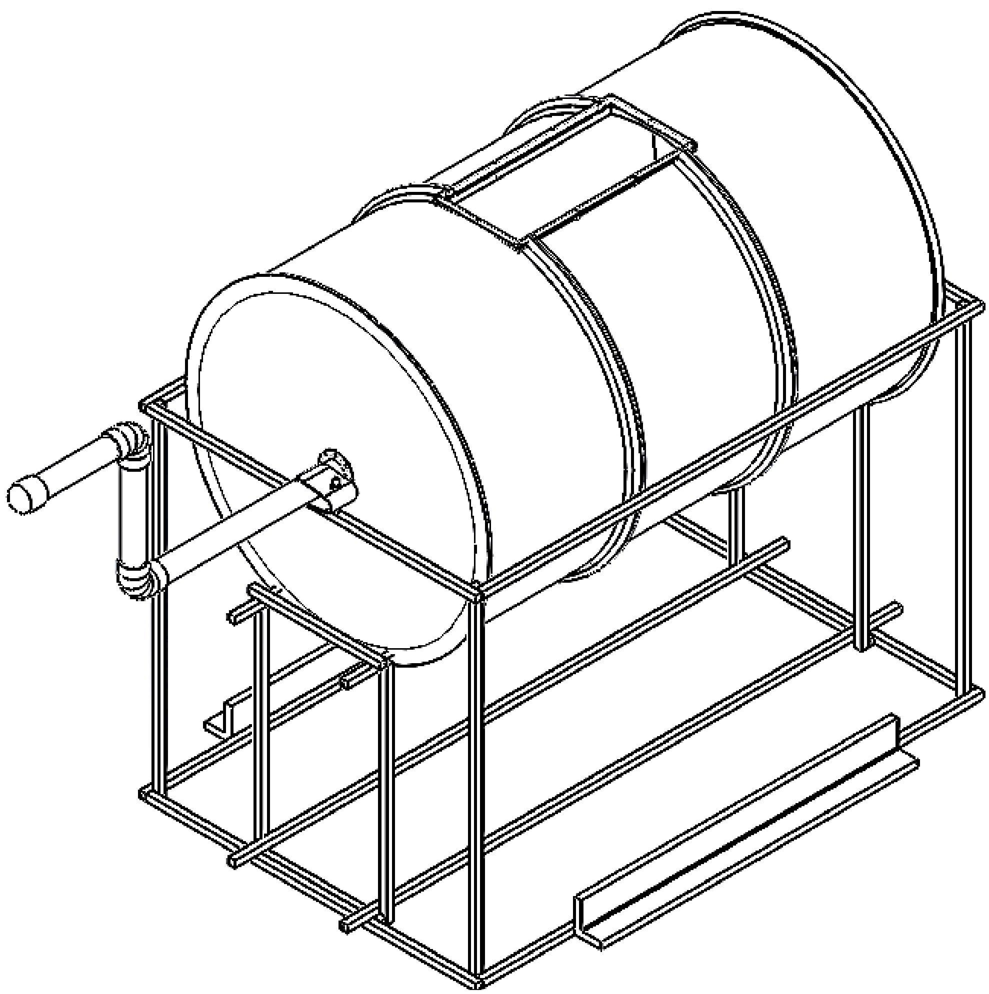
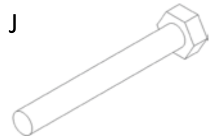
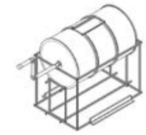
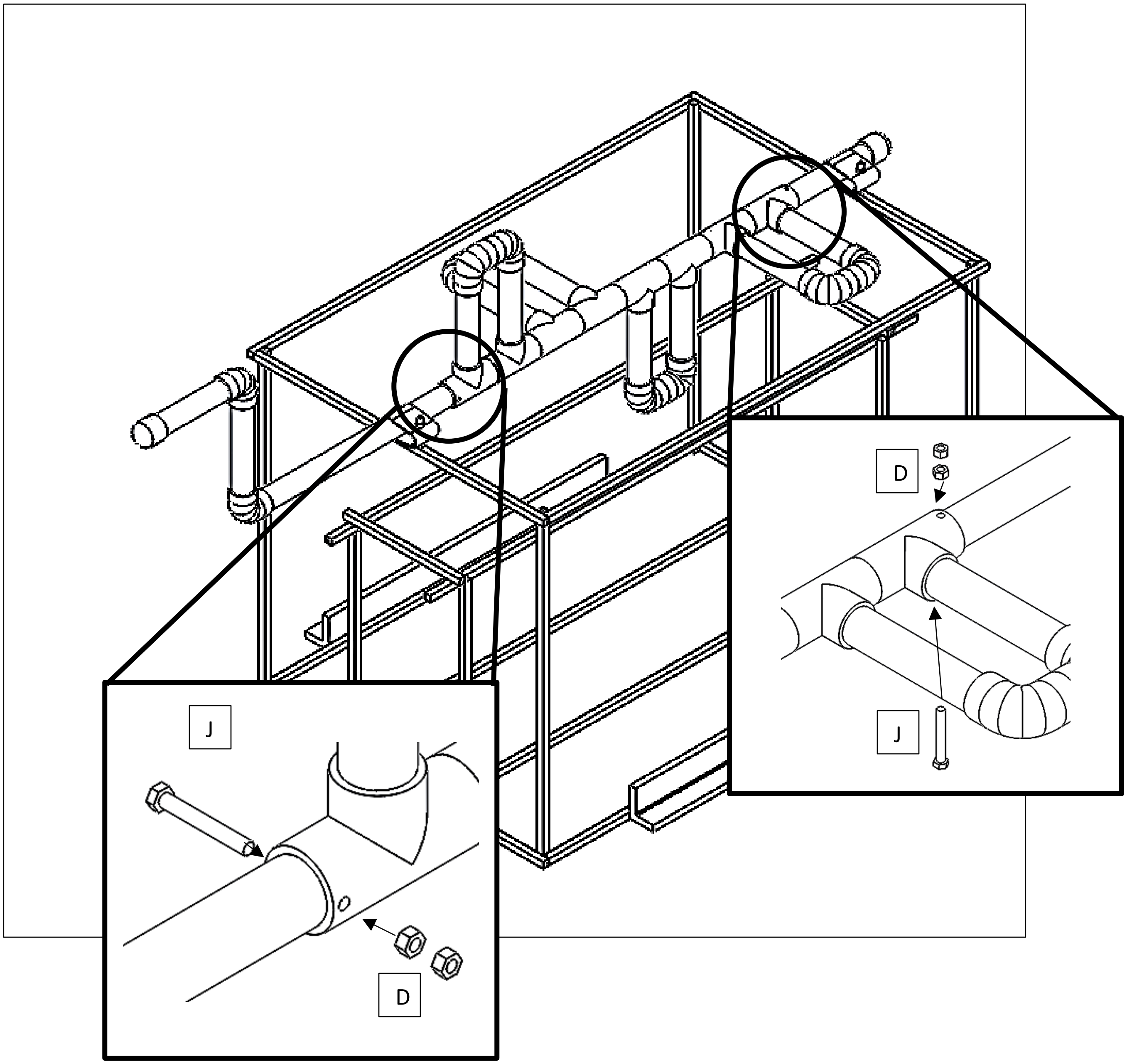




7)	D  x4	J  x2	



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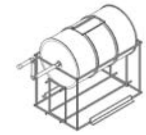
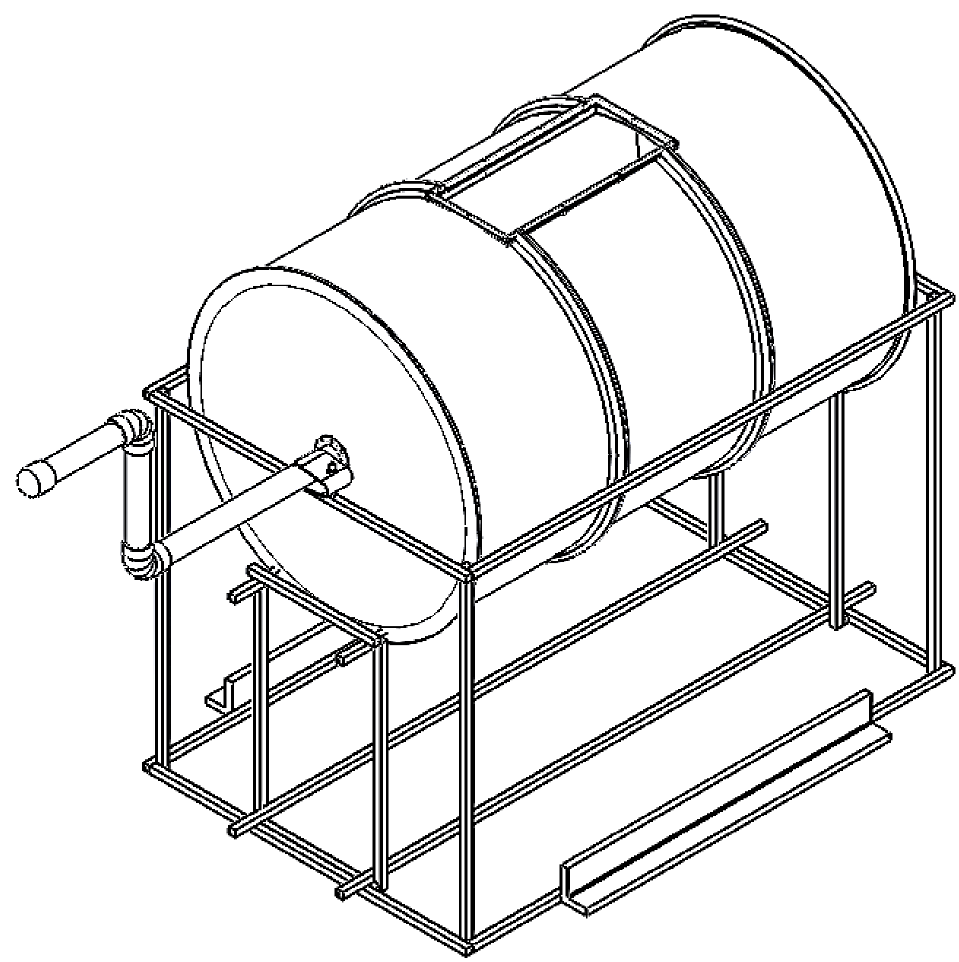
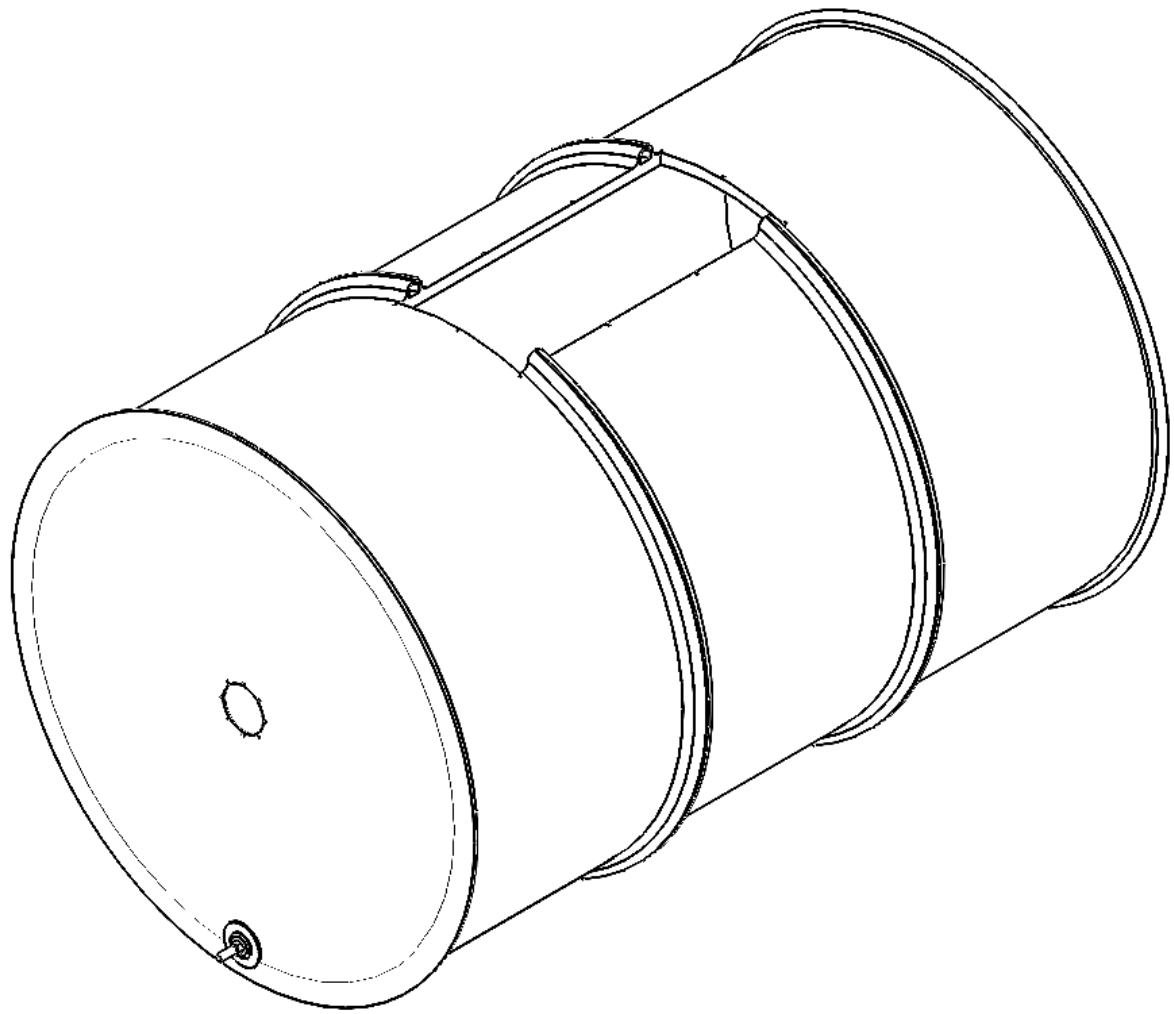
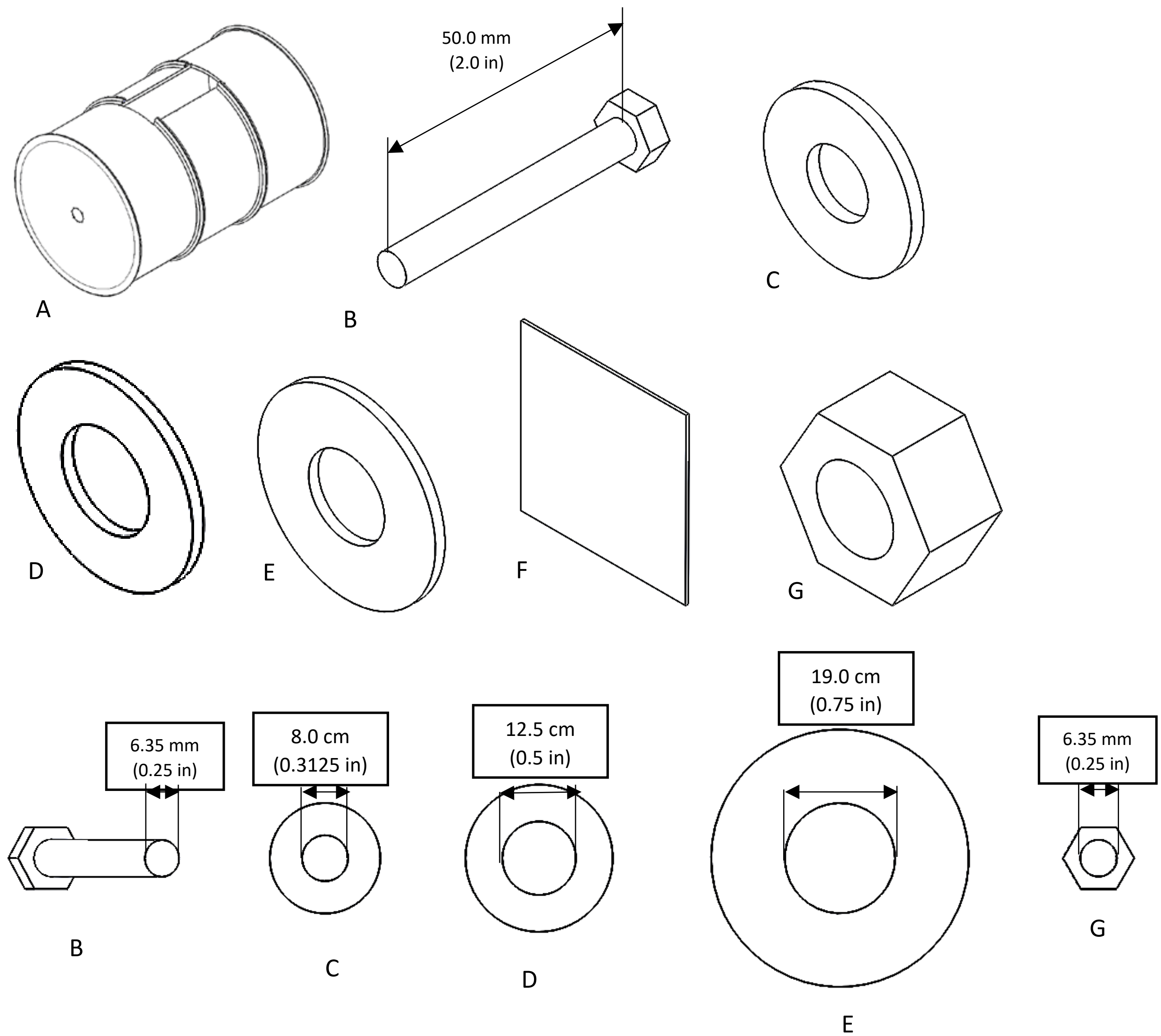




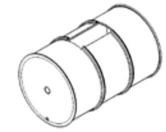
Plug (Optional):

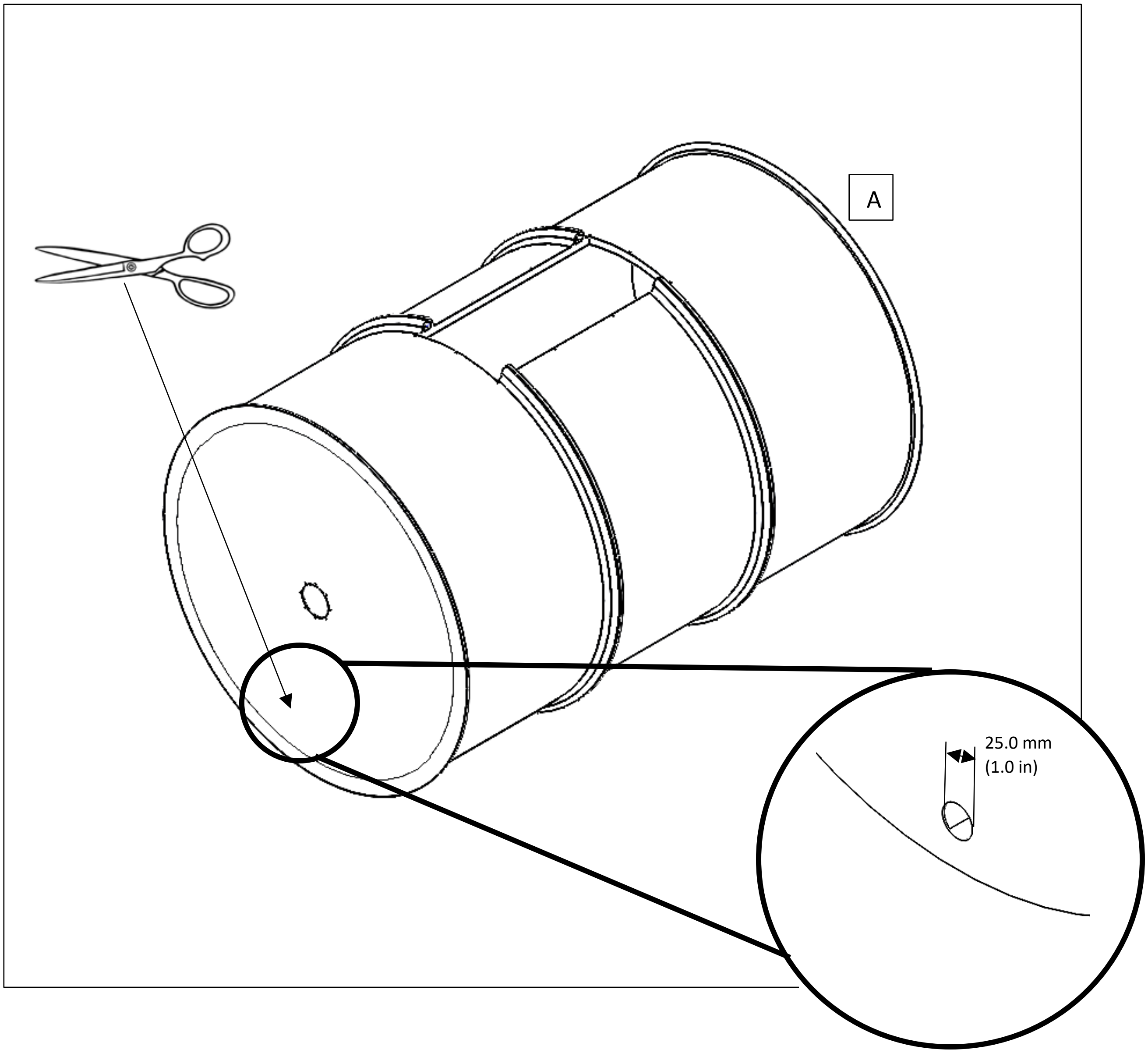


Bill of Materials:



A	x1
B	x1
C	x2
D	x2
E	x2
F	x1
G	x1

1)	A  x1	



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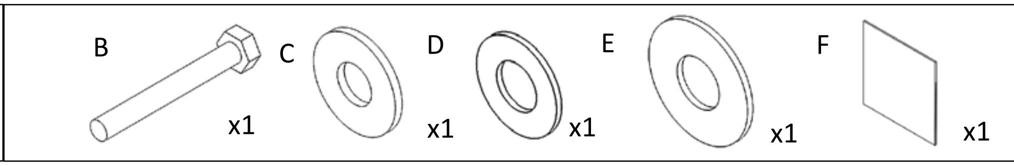
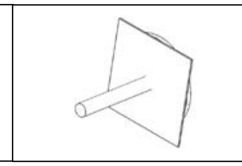
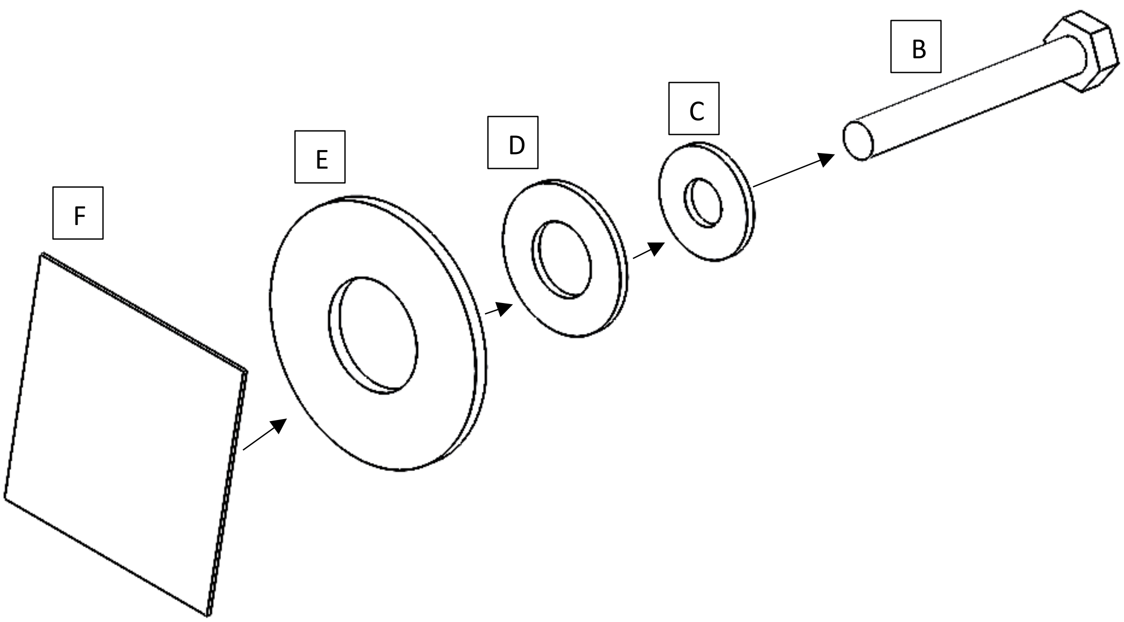
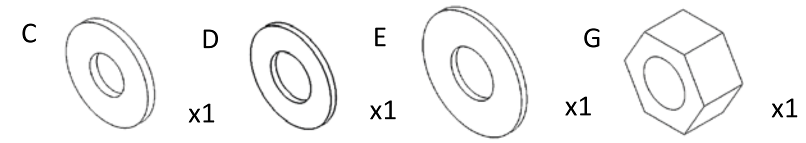
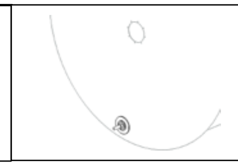


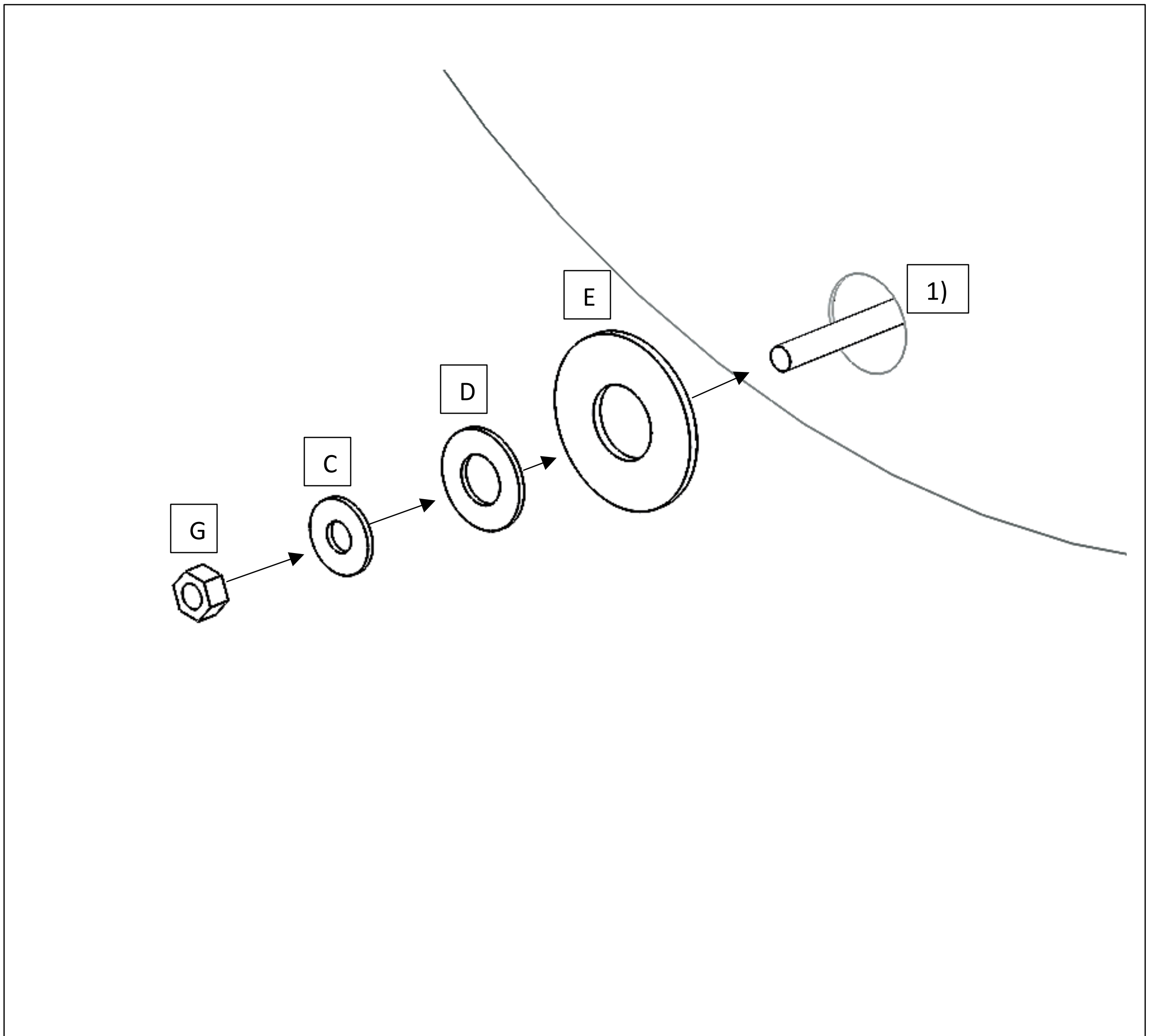




3)	C x1 D x1 E x1 G x1	







4)