



**University
of Manitoba**

FINAL DESIGN REPORT

Semi-Automatic Rocket Propellant Mixing Bowl Cleaning Design

UNIVERSITY OF MANITOBA

DEPARTMENT OF MECHANICAL ENGINEERING

MECH 4860 Engineering Design

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Executive Summary

This report contains a semi-automated cleaning system for Magellan Aerospace's propellant mixing bowl. The final design eliminates the need for an operator to climb into the bowl to clean it, increasing the safety of the cleaning process.

The final design consists of 4 major design components including, the Teflon coating, the mechanical scraping blade design, the pressurized water system, and the machine components required for a transmission shaft. The Teflon coating decreases the total friction forces by a factor of 16. The mechanical scraping system consists of 6 side wall blades placed at 60° angles. The bottom scraping blades consist of 6 blades at 45° angles relative to the side wall blades, that rotate about the center of the bowl to push the propellant waste towards the center funnel, where it is collected in a waste collection system. The scrapers are made of high strength neoprene rubber and are designed to match the corner fillet radius in the bottom of the bowl. Furthermore, the pressurized water system consists of 14 different spray nozzles that spray the side walls of the bowl as well as the bottom surface. The power input for the system is a Char-Lynn S Series-103 Geroler hydraulic motor.

The mechanical scrapers, arm blades, and transmission shafts are tested using finite element analysis through SolidWorks software. The max deflection for the rubber scrapers is 0.1 inches (2.54 mm). The factor of safety for the stainless-steel shaft and blades is 3.

Lastly, a cost benefit analysis determined the project was under budget by 37% with a total cost of \$63 144 CAD. The project also gained numerous benefits through an increase in safety and reduction in total cleaning time. Similarly, a risk analysis was done and is provided for the client to consider the various risks associated with the project. The identified risks with the highest ranking include the risk of wear on the Teflon coating, the risk of cyclic failure, and the risk of inadequate setup by the operators. Mitigation for these risks include proper training for the operators and regular maintenance check ups on cleaning equipment.

The report also contains a bill of materials as well as detailed technical drawings for all major components of the design, namely, the pressurized water system, blade designs, and transmission shaft.

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1.0 Introduction

Magellan Aerospace is a Canadian space, defense, and aviation company specializing in using technological advancements for manufacturing many complex parts and systems [1]. One of the tasks performed by Magellan Aerospace at the Rockwood Plant is mixing and vacuum casting the rocket propellant fuel. The mixing is performed once a month using a 600 Gallon Baker-Perkins vertical mixing bowl. After each batch is produced, the bowl must be cleaned before it's next operation. The current cleaning process is manual and requires the operator to climb inside the mixing bowl, ensuring no residual propellant remains. Since the bowl is hot, slippery, and not ergonomic for the operator, a better cleaning process is desired.

This project aims to develop a safe and efficient design that cleans the vertical mixing bowl while eliminating the operator's need to climb inside the mixing bowl. The new cleaning system must be automated or semi-automated by applying novel techniques and must meet the customer requirements. The maximum budget for the project is \$100,000 CAD.

This report contains a design solution for cleaning the rocket propellant mixing bowl using six rotating scrapers and 14 different pressurized water nozzles to clean the inside surface of the bowl. The details of the design solution are further investigated throughout this report.

1.1 Current Cleaning Procedures

This section outlines the current cleaning process used by Magellan Aerospace to clean the 600 Gallon Baker-Perkins vertical mixing bowl. It has a working capacity of 420 Gallons and is modified by adding a ball discharge valve as shown in the Figure 1.



Figure 1: Propellant mixing bowl [2]

The mixing operation is performed once a month and is required to be cleaned before its next operation. The duration of the current cleaning process is approximately 45 to 60 minutes. After the casting process, the bowl is transported back to the mixing building where the following steps are performed in order to clean the mixing bowl:

- 1) The mixing bowl is lifted onto the cleaning stand by attaching the lifting beam to the trunnion.
- 2) A manual hydraulic lift is used to remove the stainless-steel ball discharge valve from the bottom of the mixing bowl. The discharge valve is disassembled as shown in Figure 2.
- 3) The ball discharge valve is manually cleaned by scraping off the propellant, and by handwashing with a warm soap and water solution.

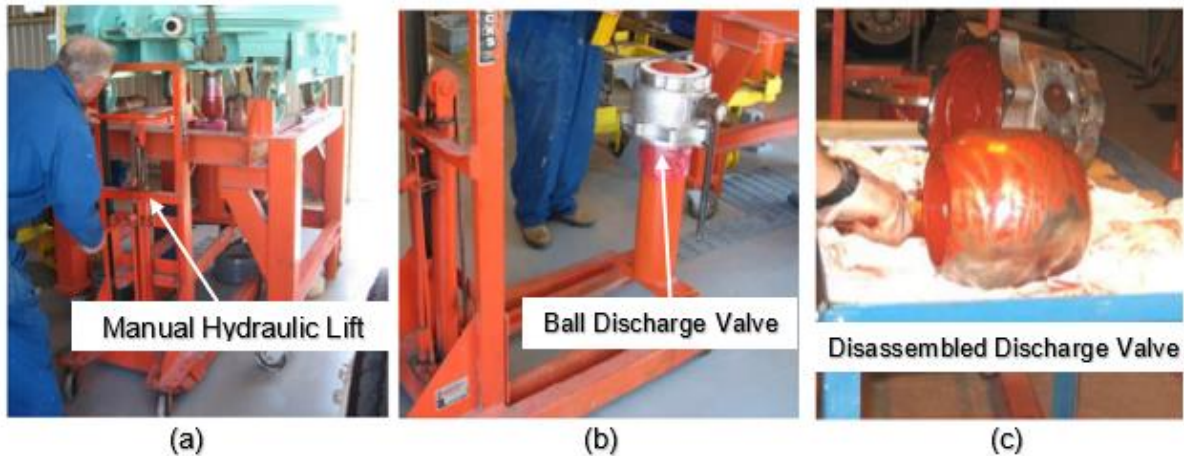


Figure 2: Removal of ball discharge valve (a) Manual hydraulic lift used to lift the mixing bowl (b) Ball discharge valve lifted onto the hydraulic lift (c) Disassembled ball discharge valve for cleaning [2]

- 4) The mixing bowl is lowered to the ground using a hoist and a waste propellant container (standard plastic tote bin lined with an electrostatic discharge bag) is placed underneath the mixing bowl at the hole location from the ball discharge valve.
- 5) The operator climbs inside of the mixing bowl and scrapes the propellant from the wall and base surface using non-sparking hand tools. The waste propellant is then pushed through the ball valve opening into the waste container lined underneath. The operator scrapes as much propellant as possible from the mixing bowl walls before proceeding to washing the mixing bowl using a soap and hot water solution and drying the mixing

bowl using hand wipes as shown in Figure 3. This ensures no water droplets are left behind before storing the propellant mixing bowl.

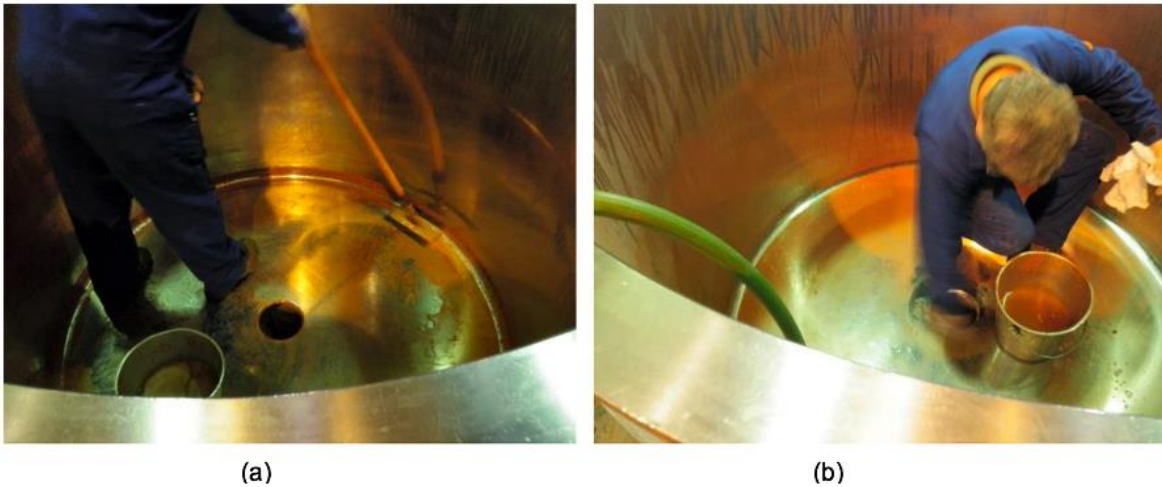


Figure 3: Washing propellant mixing bowl using soap and water; (a) Operator scrapes the propellant to remove propellant residuals from the bottom radius of the mixing bowl (b) Operator cleans the propellant residuals using soap and water solution. [2]

- 6) Finally, the waste collected underneath in the waste propellant container is properly disposed of according to Magellan's standardized work procedures.

1.2 Summary of Problem Statement

The current mixing bowl cleaning process is manual and requires an operator to climb inside the vertical mixing bowl. The cleaning operation is considered a confined space that leads to ergonomic risk factors for the operator such as prolonged awkward postures and contact stresses. Moreover, the bowl is hot and slippery which creates safety hazards for the operator. In addition, the propellant residual is flammable, potentially resulting in a risk of fire or an explosion [2]. This report will introduce a new process that eliminates unnecessary safety hazards for the operator.

1.3 Project Objectives:

The success of the project is determined by the following project objectives:

- 1) The design solution must include automation or novel techniques that remove the residual propellant from the mixing bowl while eliminating the need for the operator to climb inside the vertical mixing bowl.

- 2) The design must adhere to safety standards for a hazard class 1.3 explosive, division 2 electrical classification building, and an environmental standard as per (MR 37/2016) [3] to properly dispose the propellant waste.
- 3) The maximum project budget is \$100,000 CAD; however, if the total budget for the project exceeds the secured budget, the design solution will still be acceptable if it can be justified with a payback period of 2 years using a cost-benefit analysis.

1.4 Project Constraints:

Project constraints were identified during the initiation phase of the project to ensure that the project scope is accomplished within the given project time frame. The project constraints are outlined below.

- 1) The power source for the new cleaning process is limited to a pneumatic or hydraulic power system because electrical motors that comply with the division 2 electrical classification are hard to source [4]. The design must also avoid any energy inputs that could ignite the propellant material such as high impact forces, friction, hot surfaces, shocks, open flames, sparks, or electrostatic discharge [2].
- 2) The new design must account for the collection of explosive waste, and any contaminated materials during the cleaning process.
- 3) The design space is constrained to the existing plant, which is approximately the size of a two-story building. The new design must also fit the current dimensions of the mixing bowl with a given inner diameter of 64 inches (1625.6 mm) and inside bowl height of 45 inches (1143 mm).
- 4) As previously mentioned, the cleaning process must adhere to all the relevant safety standards from propellant class 1.3 explosive safety, and class 2 division 2 electrical classification building standards.
- 5) Due to current restrictions from the COVID-19 pandemic all meetings are required to be held remotely. This includes limiting the team to zero site visits at the Magellan Aerospace facility.
- 6) The project team is limited to four team members for the duration of the project.

1.5 Project Deliverables:

The major deliverables for the project are outlined below:

- 1) Detailed preliminary engineering drawings for the major components of the final solution that meets standards from the American National Standards Institute (ANSI).
- 2) An assembly drawing for the final design, including a detailed Bill of Materials (BOM)
- 3) A Cost-Benefit analysis and risk analysis for the final design solution
- 4) Failure Mode and Effects Analysis (FMEA) on the final design solution.

1.6 Project Assumptions:

The five assumptions made, as shown below, were identified during the planning process of the project.

- 1) The quantity of propellant mixed remains constant during each casting process. The thickness of the residual propellant in the bowl will be uniform throughout the mixing bowl.
- 2) The secured maximum budget for the project is \$100,000 CAD, which will be sufficient to find an alternative solution for the process.
- 3) The list of approved vendors or any information required from the client will be available upon request.
- 4) Since there is no CAD model available for the mixing bowl, all of the physical dimensions provided by Magellan are assumed to be accurate.
- 5) The material grade of the stainless-steel mixing bowl is unknown and will be assumed to be any reasonable grade suitable for the current mixing process.

1.7 Client Needs and Specifications

The client's needs have been organized and prioritized in order to maximize the client's satisfaction. A number five represents highest priority with a number one meaning lowest priority for the project. These priorities were established after consulting with the client and are arranged from highest priority to lowest priorities as outlined below in TABLE I.

TABLE I: CUSTOMER NEEDS

Number	Customer Needs	Priority
1	The process shall clean entire inside surface of the mixing bowl	5
2	The process shall be safe for operators	5
3	The process shall eliminate the need for the operator to climb into the bowl	5
4	The process shall provide safe transportation of hazardous wastes away from cleaning area	5
5	The process shall not generate heat to point of creating spark or explosion	5
6	The process shall work for 420-gallon Baker-Perkins vertical mixer bowl	5
7	The process shall keep the integrity of the mixing bowl	4
8	The process shall be easy and intuitive to operate	4
9	The process shall be retrofittable in the current processing plant	4
10	The process shall be durable	4
11	The process shall decrease cleaning process time	3
12	The process shall be able to deliver repeatable results	3
13	The process shall be able to work in warm environmental temperatures that are typical to the climate of southern Manitoba (building is heated but does not have AC)	3
14	The process shall be under \$100000 CAD budget	2
15	The process shall efficiently minimize operator involvement	2
16	The process shall efficiently minimize the use of consumables	2

In order to measure the project success and to ensure all the client needs mentioned in TABLE I are met, engineering metrics, with ideal and marginal target specifications were developed for the project as shown in TABLE II below. The description for the parameters used for each metric and specification are explained below.

1. The first metric used is the quality of the cleaning process. This metric will measure how often the process will pass the quality inspection performed by the client. The target specifications for this metric were based off the fact that the cleaning process happens

once a month. Therefore, a marginal pass is when the cleaning process passes the quality inspection eleven out of twelve times. This correlates to one failed inspection per year. Similarly, the ideal case is when the cleaning process fails the quality inspection once every two years.

2. The next metric is safety, which is a pass/fail option on whether the process meets safety standards from Magellan Aerospace standards, and Manitoba Workplace Health and Safety.
3. The noise level is a safety metric used to ensure that the noise created by the process will not cause hearing damage to operators. The noise level will be measured in decibels where 70 decibels is considered to cause permanent hearing loss [5].
4. The next metric, operator movement, will quantitatively measure the distance travelled by operators for the mixing bowl to be cleaned. This includes movement during setup of the cleaning system. Therefore, the movement is desired to be decreased in order to implement Lean manufacturing principles.
5. The process equipment size is a constraint that must be considered because the process is required to be retrofittable in the current plant. The process's ideal size is one in which can be transported and stored in a separate room as the mixing bowl only requires to be cleaned approximately once a month.
6. The life cycle of the process depends on the cyclic fatigue that occurs on the process equipment during the cleaning process. This will be measured in cycles, where one cycle is an entire cleaning process of the mixing bowl.
7. Similar to the life cycle metric, the stress on the equipment will measure the von mises stresses and shear stresses that the equipment experiences to determine the factor of safety of the cleaning process equipment.
8. The processing time metric will measure the time required for cleaning just the mixing bowl. The current time required for cleaning is 30-40 minutes. Therefore, a marginal target is to have the process be around 30 minutes. An ideal target is to have the process take half as much time.

9. The process's interface will determine how easy it will be for the operators to use the new process. The target specifications for this are subjective. The marginal specification would be the operators requiring a training course, and the ideal specifications would mean the operators would only need a demonstration to understand how to work the process.
10. The temperature metric measures the temperature that the process equipment must be able to handle due to the heat from the bowl and the environmental heat in the building. The specifications are based off the mixing bowl temperatures when the cleaning process is begun. This temperature after mixing is at 150°F and the temperature when the cleaning process begins is at 120°F [3]. The environmental temperatures are based off the lack of air conditioning during the summer. The building is heated to room temperature during the cold winter months.
11. The amount of explosive waste produced is desired to be minimal so that there is no extra processing required to dispose of the waste. The target specifications for waste is based off the amount of waste that is currently being produced, which is around 50-100lb. It is important to note that this weight includes the waste produced from the current cleaning process. Hence, new cleaning process is desired to create the same amount of waste as the current cleaning process [3].
12. Lastly, the cost metric is used to determine if the project is under or over budget. The target specifications for cost are based on the range of funding provided by the client.

The final specifications for the final design will be adapted after the concept design phase of the project. The metrics and target specifications are shown below in TABLE II.

TABLE II: NEEDS AND TARGET SPECIFICATIONS

Number	Needs Met	Metrics	Units	Target Specifications	
				Marginal	Ideal
1	1,12	Quality Inspection	pass/fail	92% Pass Rate	96% Pass Rate
2	2,3,4,5,13	Safety/Risks	pass/fail	Pass	
3	2	Noise Level	db.	< 70	< 50
4	15	Operator Movement	m	25	10
5	6,9	Size	ft ³	Fits in Facility	Can fit through 80" x 36" door
6	10	Life Cycle	cycles	100	250
7	7,10	Stress on equipment	MPa	F.O.S. = 2	F.O.S. = 3
8	11	Process Time	minutes	30	15
9	8	Easy Interface	subj	Requires Training	Requires demonstration
10	5,13	Temperature	deg F	61 - 120	32 - 150
11	16	Waste Produced	lb	< 150	50-100
12	14	Cost	\$ CAD	75000-100000	< 75000

2.0 Final Design

The final design integrates the use of mechanical scraping and pressurized water in a multi level rotary motion system. The design has six different blades to scrape the side walls of the mixing bowl, another six blades to scrape the bottom of the bowl, and fourteen different spray nozzles to cover the entire inside surface. Furthermore, a Teflon coating is applied to the bowl to help reduce the friction force required to remove the propellant. A hydraulic motor is the power input for the cleaning system and is fastened to the top of the lid that covers the bowl. A flexible coupling and a roller bearing are used to keep the shaft aligned during rotation. While rotating, the combination of the blades and pressurized water, will remove the propellant from the side walls and bottom surface. The blades on the bottom will then incrementally push the waste material, with each rotation, towards the hole in the center of the bowl. The waste material is then pushed through a funnel and into a waste collection system. To install the cleaning system the final assembly can be lowered into the bowl using the overhead crane and three lifting bolts fastened to the top of the lid. The cleaning system requires external hookups to a pressurized water system and a closed loop hydraulic system for the motor. After successful connections have been made there are six manual toggle clamps and two locator pins that are used to securely fasten the cleaning equipment to the mixing bowl. The final design is shown below in the colour coordinated diagram.

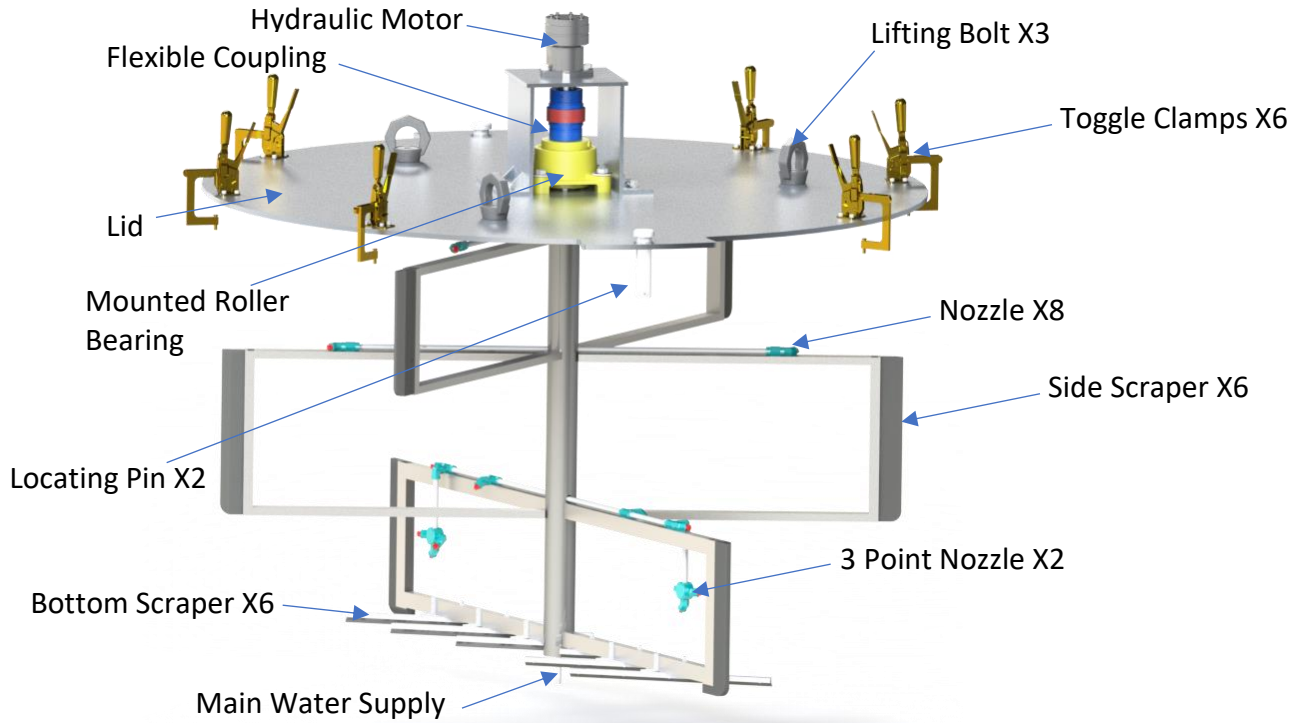


Figure 4: Rendering of the final assembly

The assembly is designed to fit the current mixing bowl and contain the explosive waste by ensuring the top of the bowl is covered by the lid and the waste material is collected and funneled into a waste collection bin. The final assembly with the mixing bowl is shown below.

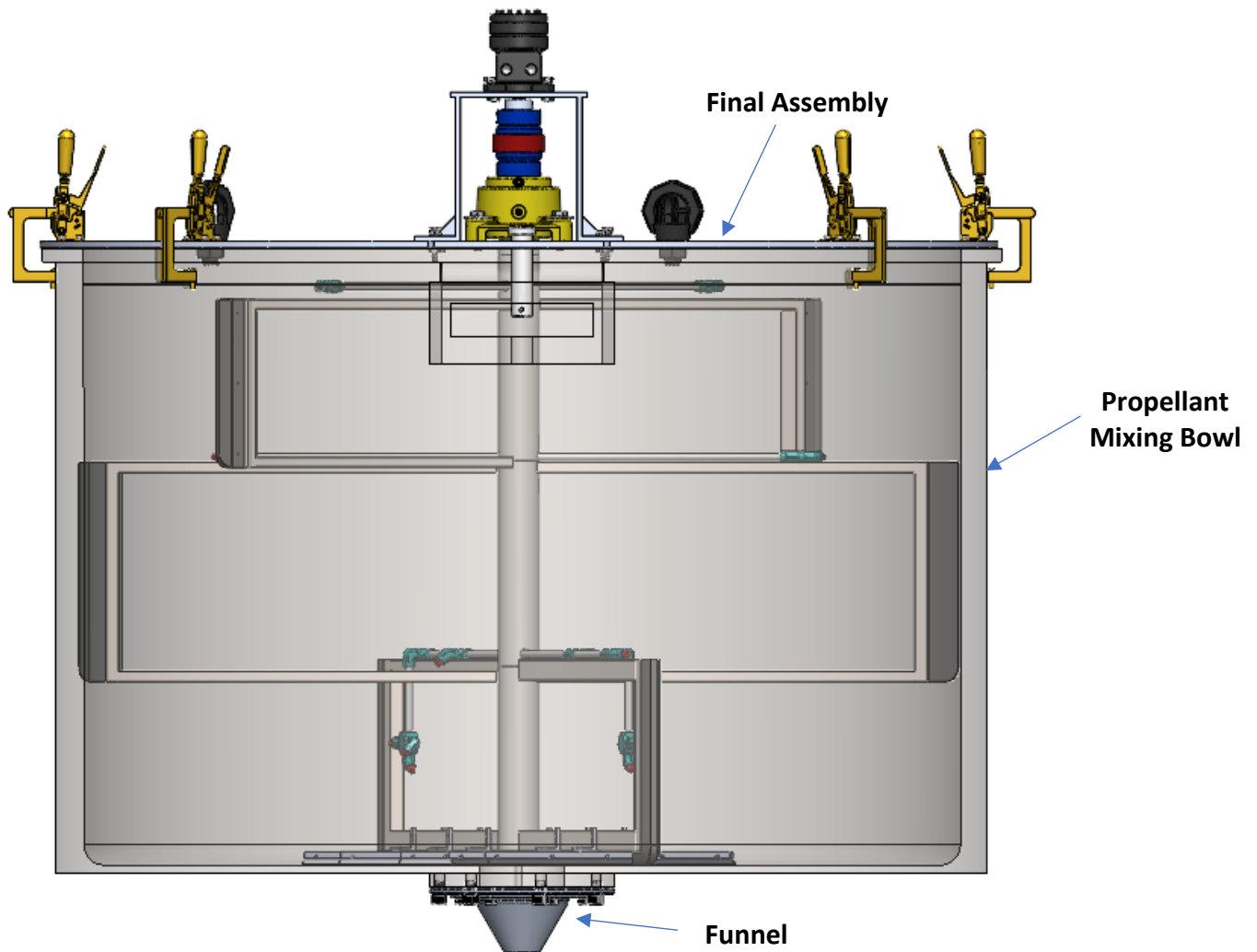


Figure 5: Propellant cleaning device on the mixing bowl.

To further explain the details of the design, the assembly components have been divided into five main parts:

1. Teflon Application
2. Hydraulic Power System
3. Pressurized Water system
4. Side and Bottom Scrapers
5. Machine Elements

2.1. Teflon Application

A Teflon coating is incorporated in the design to reduce the friction forces between the bowl surface and the propellant. Through a root cause analysis, it was determined that adding a Teflon coating provides 2 benefits to the design. The first benefit is the reduction in friction forces during the casting process. This results in less propellant needing to be cleaned off the inside surface of the bowl, which decreases the total waste. The second benefit occurs during the actual cleaning process. Due to the reduction in the friction forces, the shear force required to scrape the propellant off the bowl is reduced by a factor of 16. This is based on the comparison between the coefficient of friction values of Teflon on Teflon, and stainless steel on Teflon [6]. After reviewing with Magellan Aerospace, it was determined that the method of applying the Teflon coating was outside scope of the project. Therefore, the type of Teflon and tools for the application will be determined by Magellan Aerospace.

2.2 Hydraulic Power system

A hydraulic motor is the best power solution for a high torque, low rotational speed requirement, that meets the building's hazardous class 1.3 explosive designation. The hydraulic motor is powered by a hydraulic power pack with a closed loop system. The hydraulic motor selection and hydraulic fluid system design are outlined in the following sections.

2.2.1 Hydraulic Motor

An Eaton hydraulics Series S 103- hydraulic motor was selected for the power input system because of its high efficiency, smooth low speed operation, extended motor life, extended leak free and highly customizable hydraulic system [7]. The Series S 103 is a geroler motor rated for a torque force of 280 N-m, at a rotational speed of 7 RPM. The calculations for the required torque and rotational speed are shown in D.1 Force Evaluation. The schematic for a geroler type hydraulic motor is shown below in Figure 6.

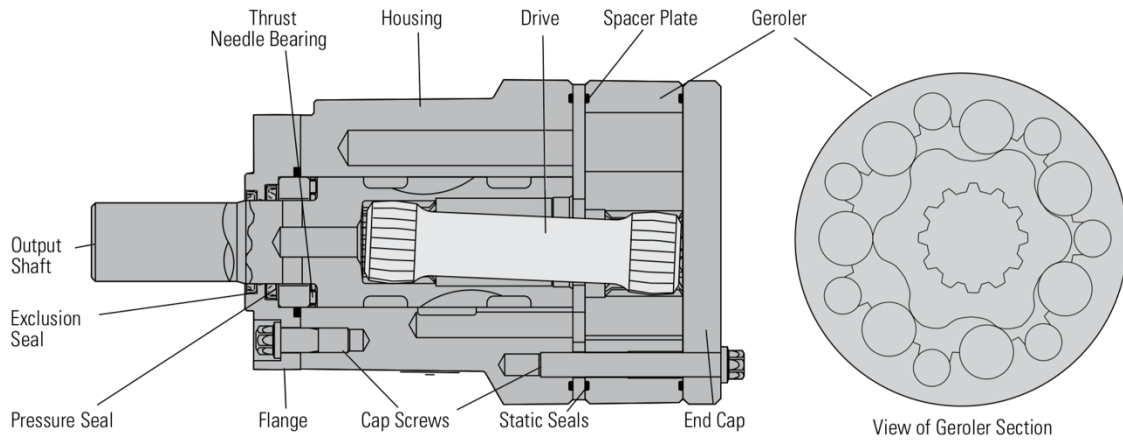


Figure 6: Geroler motor configuration [8]

A mounting plate is required to hold the motor in place due to the vertical orientation. Therefore, a mounting plate that attaches to the lid was designed to allow for proper housing of the roller bearing and coupling. Furthermore, an O-ring-152 provided from dynamic machining is installed on the pressure seal to ensure good clamping force between the mounting plate and mating surface of the motor. The mounting plate subassembly is shown below in Figure 7.

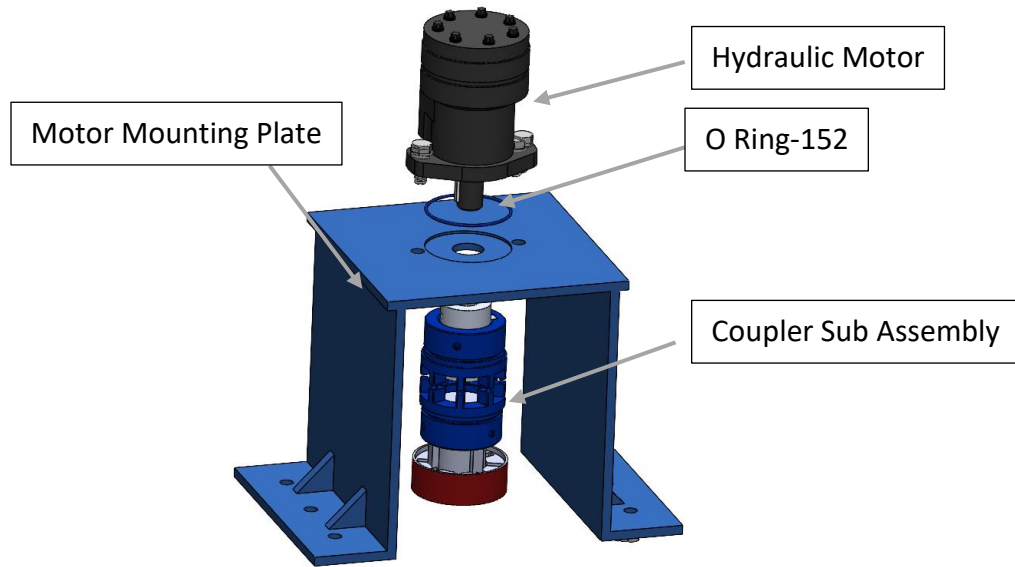


Figure 7: Subassembly of the motor mount

2.2.2 Hydraulic Power Unit

The hydraulic power unit was customized to meet the required input torque and rotation speed that was previously identified to be a torque force of 280 N-m and rotational speed of 7 RPM. The hydraulic power unit consists of a hydraulic pump with pressurized oil as the hydraulic fluid. The pumps displacement rate, pressure difference, and flow rate were all customized to fit into a closed loop hydraulic system. The customization process was performed by Dynamic Machining and the results of the different parameters are tabulated below in TABLE III.

TABLE III: DIFFERENT PARAMETERS REQUIRED FOR THE DESIRE TORQUE AND RPM

Performance Data	Value	Units
Displacement Rate	11.4	in^3/rev
Change in pressure	124	Psi
Flow	2	GPM

The closed loop system was chosen because the system is more efficient and provides more precise motor control than an open loop system. Furthermore, the closed loop system is

less expensive and requires less maintenance [9]. The schematic for the closed loop hydraulic system is shown below. in Figure 8.

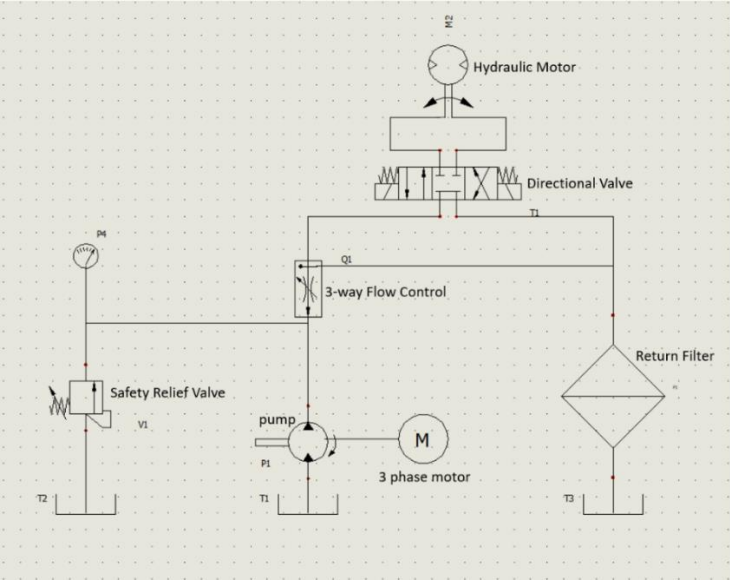


Figure 8: Hydraulic power system [10]

A similar hydraulic power unit obtained from Dynamic machining is shown below in Figure 9.



Figure 9: Similar hydraulic power pack made by Dynamic Machining [10]

2.3 Pressurized Water System

A pressurized water system is included in the design solution to help remove the residual propellant. The pressurized water system includes 14 different nozzles with 6 distinct branches located at 60° angles from the center shaft. This allows for the entire inside surface of the bowl, including the bottom surface, to be sprayed with the pressurized water. The piping is made from stainless steel tubing and is routed through the main shaft so that it can be concentric with the shaft during rotation. Stainless steel was chosen for the piping material due to its high corrosion resistance and its availability to be sourced. The process for the pressurized water system can be found in Appendix C: Pressurized Water System. The entire assembly of the pressurized water assembly is shown in Figure 10 below.

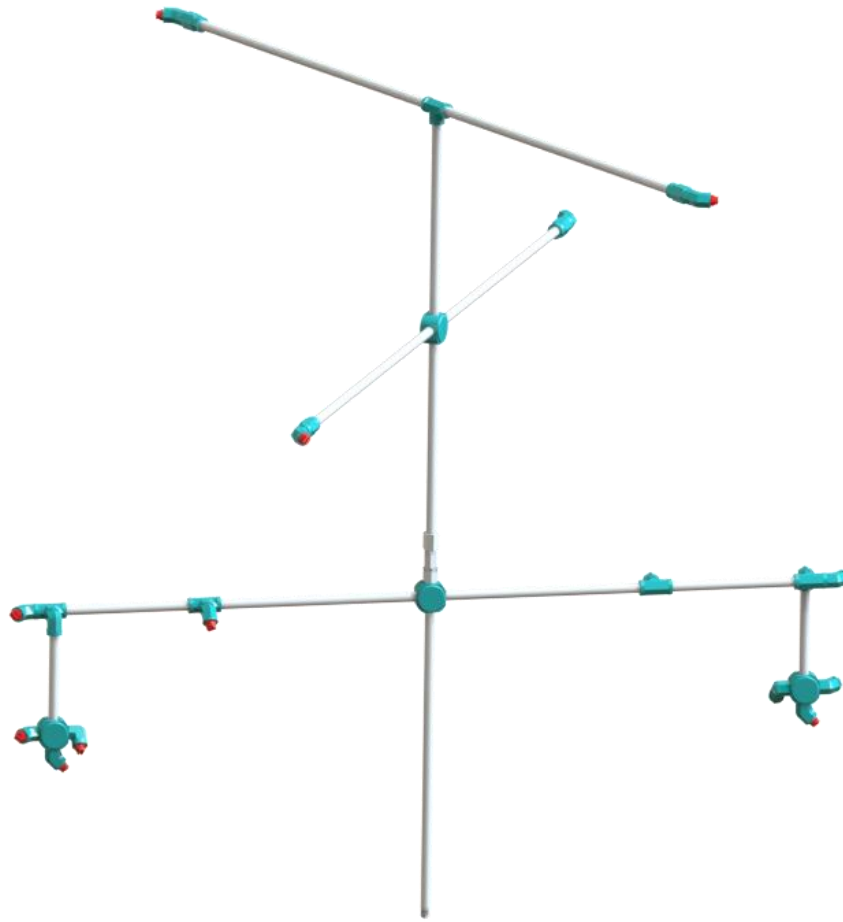


Figure 10: Pressurized water systems with colour coordinated components

The nozzles selected for this design are the high-pressure flat spray nozzles, with a 65° spray angle, in order to accommodate the large area. The nozzles are also placed such that they aim 45° in front of the scraping blades. This is so that the water can effectively shear the propellant of the surface rather than contacting the surface perpendicularly. Furthermore, calculations were done to determine the distance from the radius of the bowl to the location of the exit nozzle. This ensures that the spray will cover the entire surface, in the vertical direction, while spinning. The bottom horizontal branch of the piping system includes 5 nozzles on each side. Two of the 5 nozzles spray the bottom 32 inches (812.8 mm) of the bowl radius, while the other three nozzles spray the bottom side-wall section, and the corner radius. The nozzle for the corner radius is a single stream jet rather than a flat spray. This is because a jet stream will

blast the bulk of the material away from the edge of the bottom scraping blade. The bottom horizontal branch 3-point nozzle system is shown below in Figure 11.



Figure 11: Bottom branch nozzles (colour coordinated)

The water system has an external connection point through the opening of the ball valve hole. Furthermore, the connection point includes a swivel joint so that while rotating the external water piping will not rotate with the cleaning system. The nozzle location calculations can be found in Appendix C.3 Spray Nozzles Calculations.

Computational Flow Analysis was performed on the pressurized system in order to fully optimize the fluid flow and ensure a proper pressure distribution throughout the design. With an inlet flow of 2400 psi, the system required a reducer after the first cross connection point so that the bottom branch could receive a majority of the pressure distribution. This is because the bottom branch has 5 nozzles compared to the top and middle branches only having one per branch. The computational fluid simulation results can be found in Appendix C.

Lastly, the water system is constrained to the mechanical systems of the design by rubber grommets at the holes of the shaft. This is to prevent the water system from rubbing or abruptly contacting the shaft. The total assembly and bill of materials is shown in the drawing below.

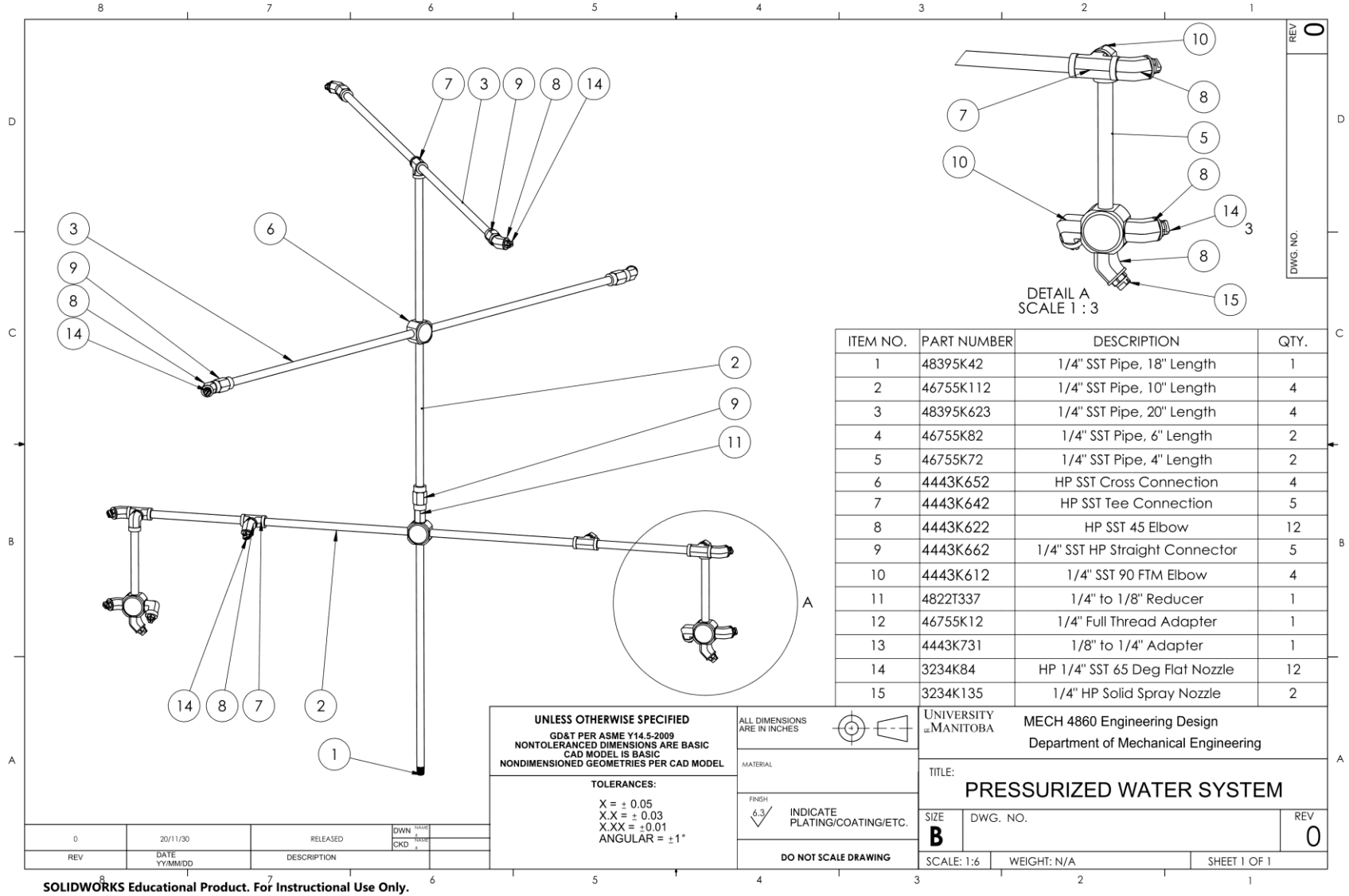


Figure 12: Technical Drawing of Pressurized Water System

2.4 Mechanical Scraper Blades

There are total 12 scraper blades made from high strength neoprene rubber that remove the residual propellant from the inside surface of the bowl. The arms of each blade are made from 316 stainless steel and are welded to the main shaft. Six arms are used to keep rotational balance and are located at 60° angles from each other. The bottom blades each have 3 rubber scrapers mounted at 45° angles to push the propellant towards the funnel as the system rotates. The rubber edges are beveled to help shear the propellant and the bottom corners are filleted to prevent the blades from hitting the lip of the bowl when the cleaning assembly is being lowered into the bowl.

2.4.1 Side Wall Blades

The side wall scraper blades are designed to scrape a 15-inch (381 mm) section of the bowl while rotating. Therefore, the bowl height was divided into three distinct sections. That is, the top, the middle, and the bottom section. This is illustrated in Figure 13.

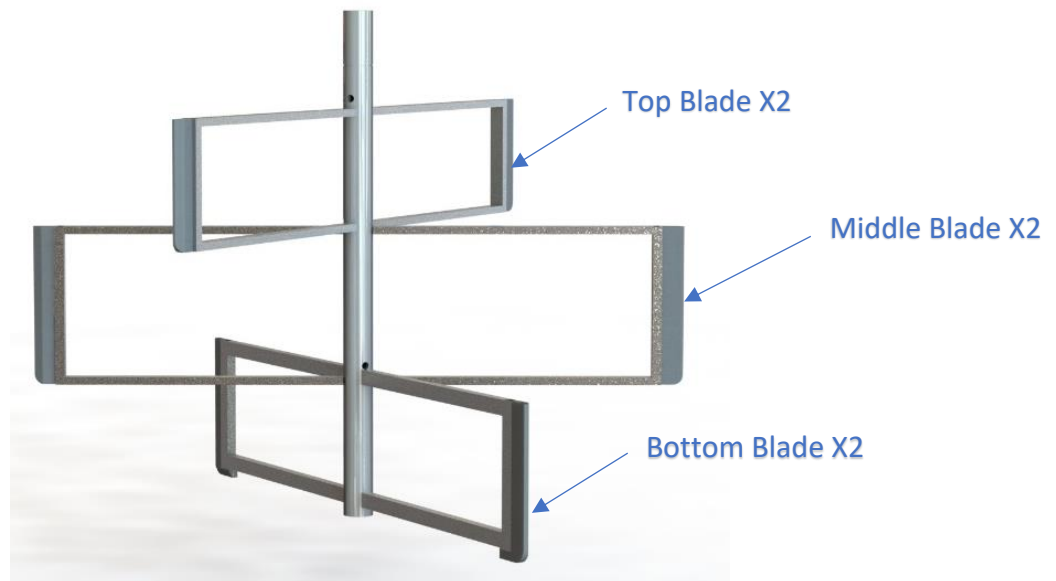


Figure 13: Overview of side scrapers

The blade heights for the bottom and middle blades are 15 inches (381 mm), but the top blades are only 12.3 inches (312.42 mm) in height because the top 2.7 inches (68.58 mm) of the bowl

is not covered in propellant during the mixing phase. The blades are designed from 3 different pieces of stainless steel rectangular hollow tubing. As previously mentioned, the rectangular tubing is welded together and then later welded to the main shaft. Furthermore, a T-bar is welded to the face of the vertical rectangular tube to allow for the fastening of the rubber scraper. The T-bar essentially acts as a key for the rubber piece. The blades were designed using rectangular tubing to save on material costs and because the transmitted torque force is carried on the outer thickness of a material. Thus, any material in the center of an object is wasteful. The detailed material selection for the blades and the rubber scrapers is shown in Appendix G: Side Blades Detailed Design.

The horizontal orientation of the blades is designed to minimize the deflection while scraping the propellant. The stress profile and total deflection of the blades, and the rubber scrapers, were tested in SolidWorks FEA simulations. The max stress in the blade was determined to be 1160 psi (8 MPa) and the max deflection was 0.02 inches (0.508 mm). This was well within the acceptable range of criteria. The FEA simulation results can be found in the Appendix I: Finite Element Analysis. The assembly drawing for the total welded assembly of the blade arms to the main shaft is shown below.

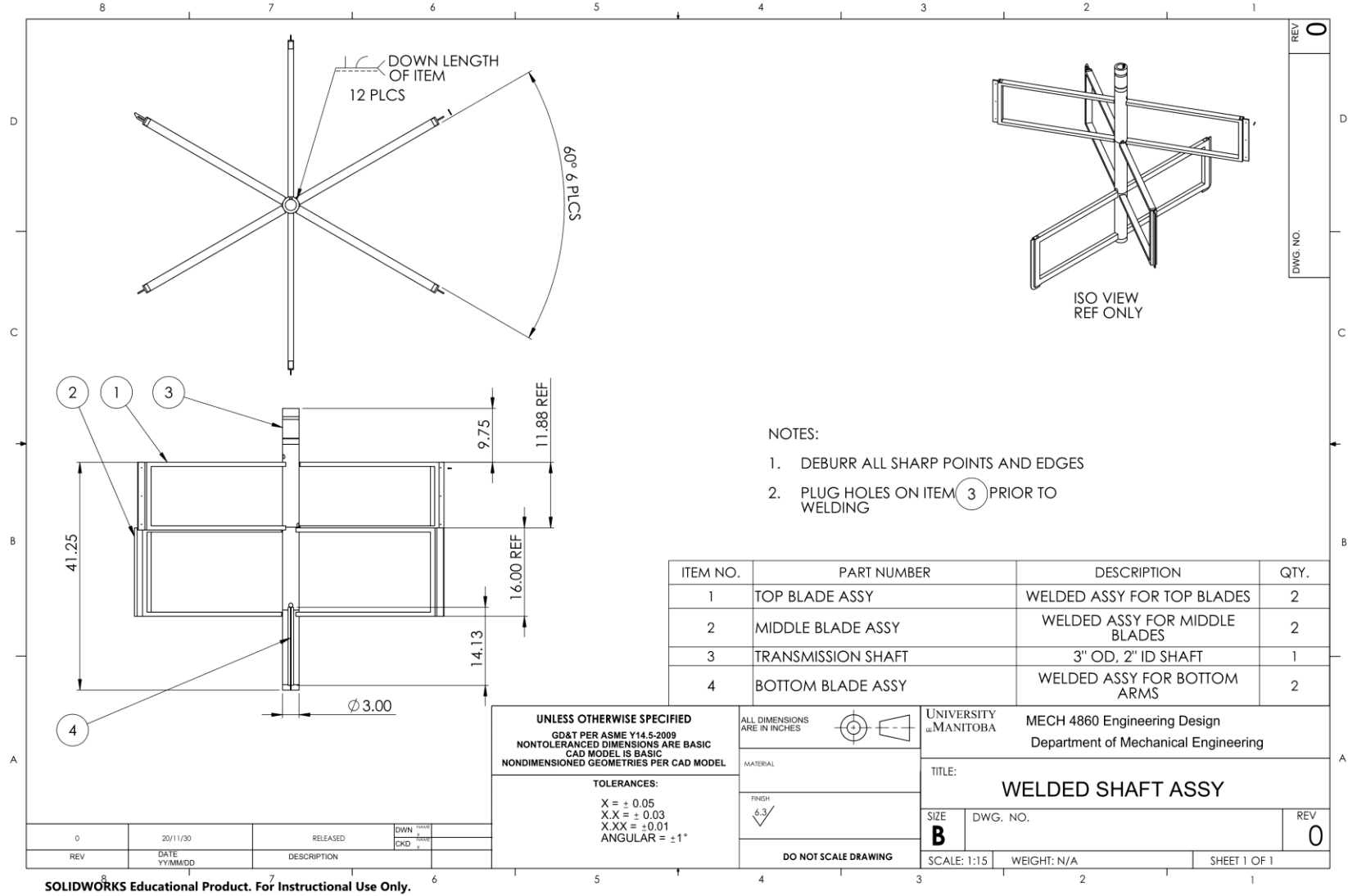


Figure 14: Technical drawing for welded shaft assembly

2.4.2 Bottom Scrapers

There are six scrapers that clean the bottom of the bowl that are orientated at 45° angles relative to arms of the blades. The angled scrapers were designed so that the geometry of the side wall scrapers could remain simple. The bottom scraper blades consist of two 20-inch (508 mm) and one 10-inch (254 mm) 316 stainless steel arms. These arms are fastened to the bottom of the rectangular tubing using an L-bracket on both sides. The L-bracket is pre-drilled to match the locations of the holes in the arms and are fastened to each scraper using stainless steel hardware. Each scraper arm is attached to a 45° beveled piece of high strength neoprene rubber. The stainless-steel arms and rubber scrapers can be seen below in Figure 15.

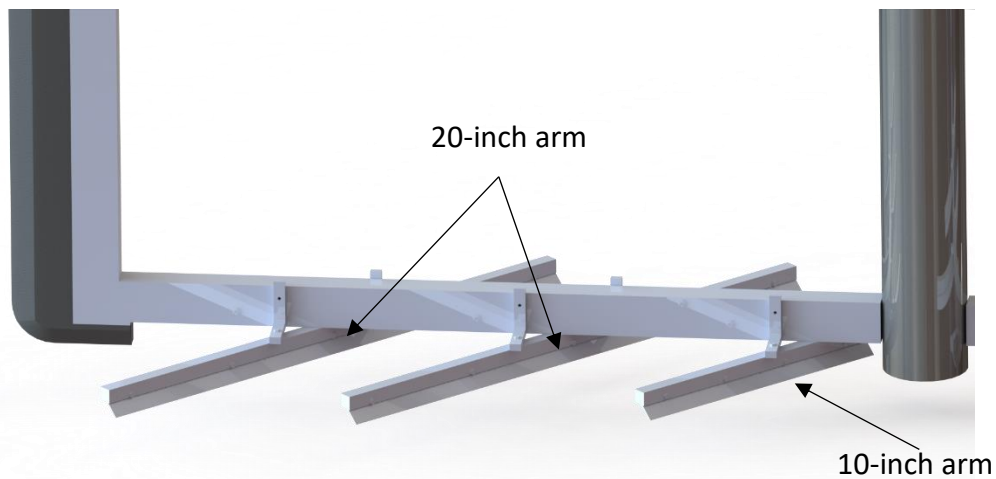


Figure 15: Bottom scraping blades

The bottom scraper arms decrease in size so that the time exposure profile of a cycle pushes the material towards the funnel. The bottom scraper orientation is shown below in Figure 16.

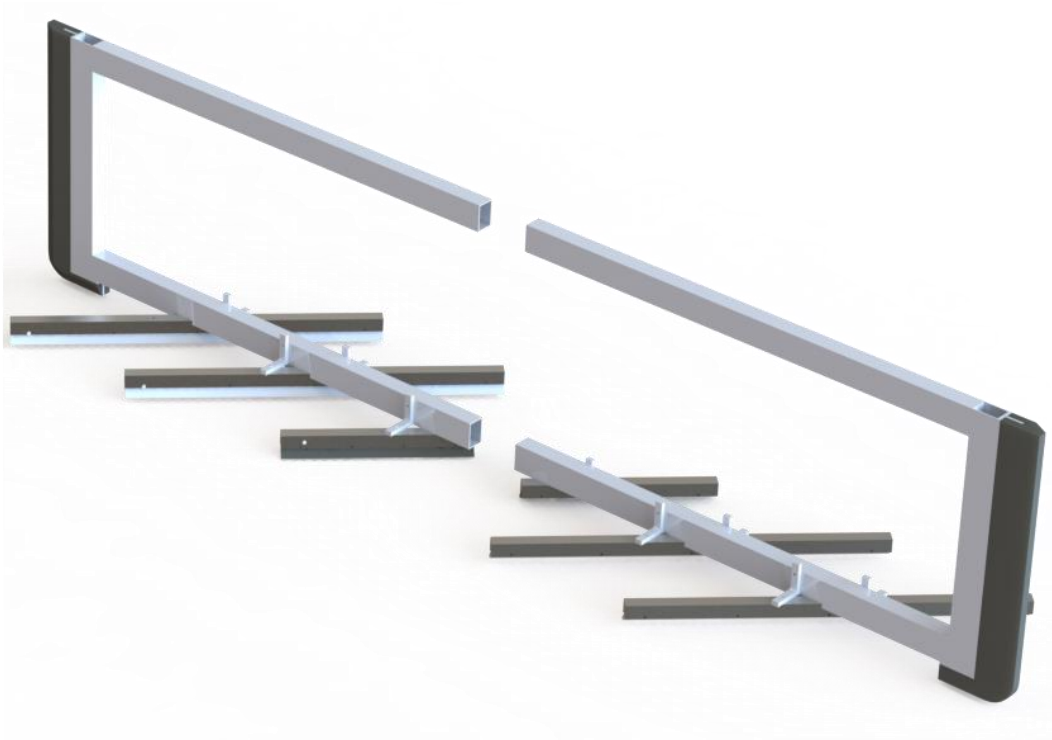


Figure 16: Bottom scraper final assembly orientation

FEA was simulated in SolidWorks software to determine the forces experienced on the bottom scrapper arms and the rubber pieces. The results for the scraper arms yielded a factor of safety of 5, and a max stress of 700 Psi (4.8 MPa). Furthermore, in order to maintain perfect contact with the bottom of the bowl the team constrained the design of the rubber scrapers to have a maximum deflection of 3mm. The FEA simulation resulted in a maximum deflection of 0.08 inches (2.032 mm) with a safety factor of 3. The detailed results of the FEA simulations are found in Appendix I: Finite Element Analysis.

2.5 Machine Elements:

This section provides details on the design of the various components not directly involved in the cleaning process. This includes the design of the transmission shaft, the roller bearing, flexible coupling, and the assembly lid.

2.5.1 Transmission Shaft

The transmission shaft is a hollow 316 stainless-steel shaft with an outer diameter of 3 inches (76.2 mm) and an inner diameter of 2 inches (50.8 mm). The shaft is hollow to allow for

the routing of the pressurized water system. Furthermore, the shaft has three 1-inch (25.4 mm) holes located 15 inches (381 mm) apart for the branches of the water system. The calculations for determining the minimum shaft diameter and the wall thickness are found in Appendix D: Shaft Design Details.

The design of the shaft included identifying the total amount of forces applied on the shaft from all 6 of the side blades arms. To ensure that failure was highly unlikely, the minimum factor of safety was set at 3 and the reaction forces at each location of the shaft were analyzed using both hand calculations and FEA simulations. The total torque experienced by the shaft was 240 N-m which satisfied the criteria for the minimum factor of safety. The results of the FEA also determined the max deflection at the free end of the shaft to be 0.004 inches (0.1016 mm). The details on the hand calculations and FEA simulations can be found in Appendix D: Shaft Design Details.

The endurance strength of the shaft was determined to ensure that the shaft will have an infinite lifespan. However, when determining the endurance strength there was several factors that were considered. The shaft was considered to have a machined outside surface, experience bending moments, and work in temperatures of 120 degrees F. Therefore, the following factors were set.

1. A surface modification factor was set at 0.267
2. A size factor was evaluated as 0.79
3. A temperature factor was set at 1.01
4. A reliability factor of 99% was set at 0.753

Therefore, after considering all the applicable factors and that the cleaning system was expected to operate approximately 20 minutes per month, with an infinite design life, the endurance strength was calculated to be 48.24 MPa. Furthermore, the minimum shaft diameter using DE-Goodman failure criteria resulted in a minimum outer diameter of 2.5 inches (63.5 mm) [11]. To account for any unexpected stress concentrations or material cracking, the final outer diameter was set at 3 inches (76.2 mm).

2.5.2 Key, Keyway, and Key seat

A 0.75-inch (19.05 mm) long square key with a 0.5-inch (12.7 mm) width and height was placed at the hub section between the main transmission shaft and the coupling shaft to allow for power transmission. The dimensions for the key and key seat were designed according to the information obtained from the Machinery Handbook [11]. The most common type of key for shafts up to 6.5 inches (165.1 mm) in diameter was determined to be a square key. Furthermore, the standard key dimensions for a 2-inch (50.8 mm) diameter shaft would be square key that has a height and width of 0.5 inches (12.7 mm). The minimum key length was determined to be 0.57 inches (14.48 mm) but to design conservatively the key was chosen to be a standard size of 0.75 inches (19.05 mm). The calculations for the key dimensions can be found in Appendix F: Key selection for shaft and hub. Moreover, to avoid catastrophic failure the material for the key was chosen to be SAE 303 stainless steel. This ensures that the key is the weakest material in the power transmission system. The final dimensions of the key and key seat are shown below in Figure 17.

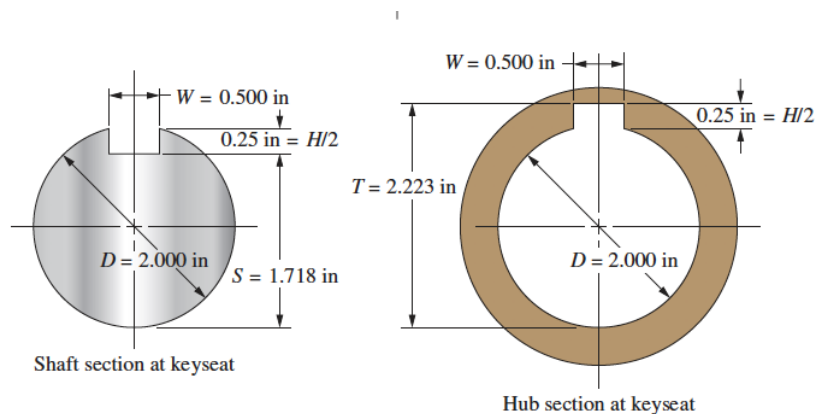


Figure 17: Key and key seat design [12]

2.5.3 Coupling Design

A high torque flexible coupling from McMaster Carr was chosen to couple the motor with the main transmission shaft. The flexible coupling covers an angular misalignment of 2° and provides a parallel misalignment of 0.039 inches (0.99 mm). Based on the torque requirement of 280 N-m, the high torque split spider coupling was determined to be the best coupling for this application. The main coupling material is made from urethane which

withstands repeated use and dampens vibrations in the shaft. Furthermore, the coupling is easily sourced and can handle torque forces up to 390 N-m. The type of coupling used is shown below in Figure 18.

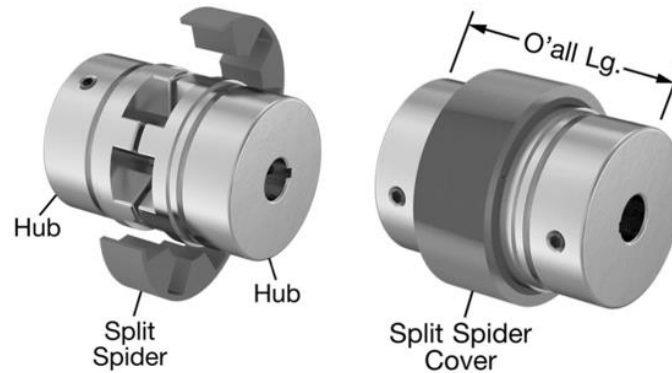


Figure 18: High torque flexible coupler [13]

A detailed design of the coupling included placing a retaining ring on the shaft near the bearing location to prevent the axial movement of the shaft. The retaining ring was added to resist the forces generated from the weight of the cleaning system during the process of installing the equipment. The retaining ring is an external retaining ring made from 15-7 Ph stainless steel with Rockwell hardness of C43 and thrust load capacity of 33,300 lbs. The total weight of all the cleaning equipment was determined to be 305 lbs.

An O-ring was installed at the groove of the hydraulic cylinder to provide a compressive force when the motor is clamped to the upper mounting plate. Furthermore, the O-ring helps to create a tight seal that prevents power losses from the motor to the main transmission shaft. The O-ring-152 was chosen for the design based on the technical information on the drawing as shown in Figure 19 below and the final coupling subassembly is shown below in Figure 20.

2 Bolt Flange

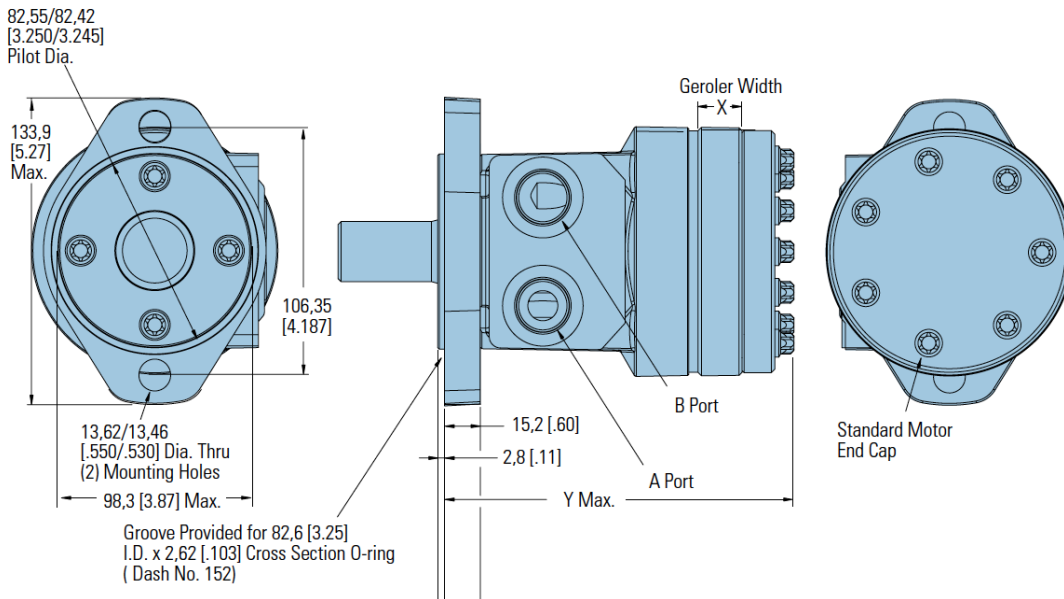


Figure 19: Geroler motor drawing identifying the recommended O ring [14]

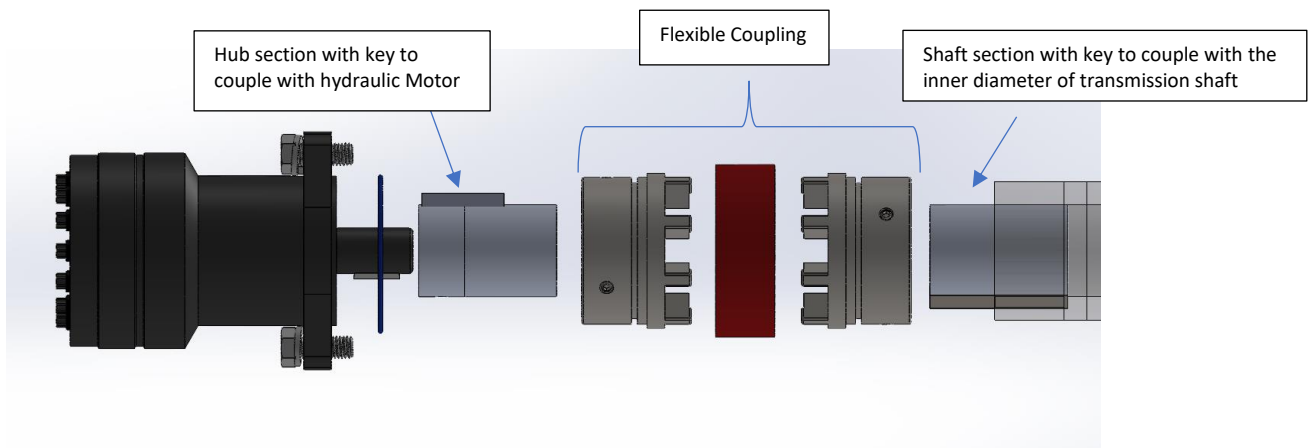


Figure 20: Coupling Subassembly

2.5.4 Bearing Design

The main requirement of the bearing design was to support the radial and thrust loads while allowing very small misalignments. Therefore, a mounted 4-bolt flange tapered roller bearing was selected for the main shaft diameter. The roller bearing was source from McMaster-Carr and can handle dynamic radial loads and thrust loads of 12,300 lbs and 5150

lbs, respectively [13]. The bearing is mounted directly onto the lid of the cleaning machine with a ½-13 UNC bolt as shown in Figure 21.

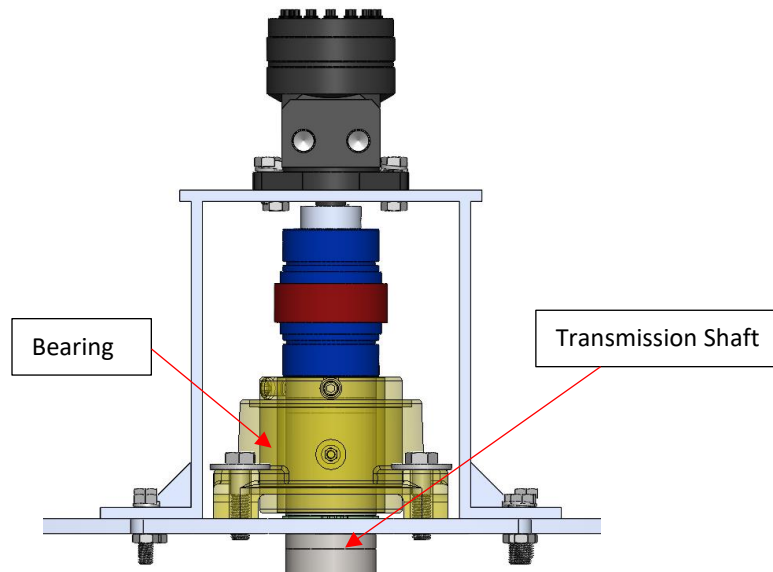


Figure 21: Bearing Connected On The External Diameter Of The Transmission Shaft

The recommended design life for the bearing was considered to be 30,000 hours based on the recommended design life for the bearing on a similar application for a general industrial machine as per table 14-4 in the Machinery Handbook. A reliability factor of 95 % was used and identified to be 0.62 as per table 14-6 for life designation [11]. The equivalent load for a tapered roller bearing was calculated to be 142 lbf as shown in Appendix G: Side Blades Detailed Design. Furthermore, a basic dynamic load rating was calculated to ensure that the selected bearing was satisfactory for the design and it was evaluated at 262 lbf. This result was significantly below the rated dynamic thrust load capacity and the dynamic radial load capacity.

2.5.5 Lid Components

The lid was designed in order to fix the position of the cleaning assembly in the mixer bowl. The lid itself contributes to aligning the main shaft with the center hole of the bowl. Furthermore, this included the centering of the, pressurized water line system, the side scrapers, the bottom scrapers, and the hydraulic motor. The main components of the lid are as follows:

1. Rotating eyebolts for lifting: There are 3 rotating eyebolts located at 120 degrees apart from each other. The eyebolts can be securely fastened to the lifting crane during the transferring process of the cleaning equipment. The equipment will be lifted and transferred into the mixing bowl for the cleaning operation and removed once the cleaning operation is completed.
2. 1.5-inch dowel pin: The 1.5-inch diameter dowel pins are used for locating the cleaning system into the mixing bowl. The dowel pins were designed to be retrofittable on the current mixing bowl and the pins constrain 5 of the 6 degrees of freedom.
3. Toggle clamps: Toggle clamps were used to constrain the vertical translation movement. These toggle clamps were sourced from McMaster-Carr and modified to sufficiently clamp the thickness of the lid with the lip of the bowl. Furthermore, the toggle clamps constrain the last degree of freedom that the dowel pins did not.
4. Holes for bearing location: A bearing housing with four bolt flanges are located at the centre of the bowl supporting the axial and radial load. This was done to add simplicity for the first-time installation process.
5. Mounting plate for motor: As previously mentioned there are holes to help locate the correct placement of the mounting plate for the hydraulic motor.

A complete lid assembly is shown below in Figure 22.

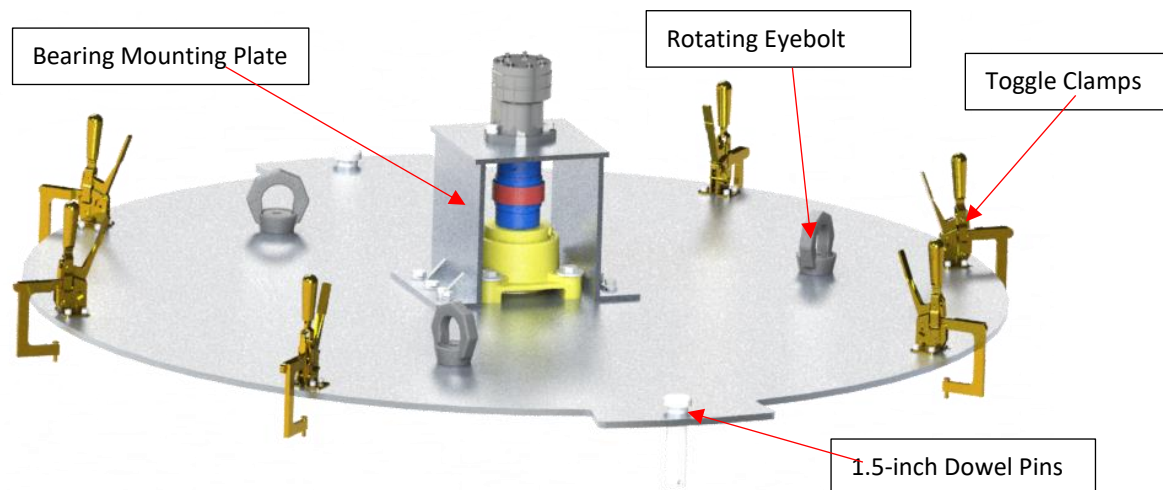


Figure 22: Lid and its components

2.5.6 Waste Collection Funnel

A funnel was included in the design to guide the waste propellant and wastewater into the waste collection system. The funnel was designed to be retrofittable at the ball valve opening using the existing tapped holes. The funnel constructed out of aluminum and weighs 4.5 lbs, making it easily removable. The funnel mounting plate is shown below in Figure 23.

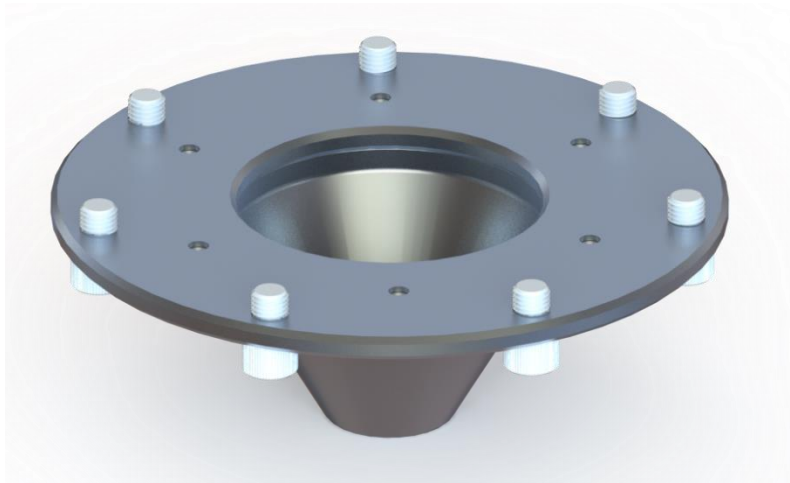


Figure 23: Retrofittable funnel

3.0 Cost Benefit Analysis

This section provides the detailed information on the design solution from financial point of view, which contributes to the success of the project. Therefore, a detailed cost-benefit analysis was done so that client can identify the feasibility for creating a prototype of the cleaning solution.

3.1 Total Cost

The total secured budget for the project was \$100 000 CAD. The cost of the entire assembly was calculated based off the current market prices and resulted in a total design cost of \$63 144 CAD. Any custom-made parts were quoted from local vendors in Winnipeg and any costs based on past market costs were adjusted for inflation. More details on the quotes for various components provided by the local vendors can be found in **Appendix J**: Detail Cost Analysis. The total cost of the semi automated propellant cleaner was divided in 4 main parts: the Teflon coating application, the hydraulic system, the mechanical components and the pressurized water system. The results are tabulated below.

TABLE IV: TOTAL COST OF SEMI-AUTOMATED PROPELLANT CLEANING DEVICE

Description		Cost (CAD)
Teflon Coating		5068
Hydraulic System		14000
Mechanical Component	Purchased part	5063
	Designed/Manufactured Parts	34752
Installation Cost		2000
Pressurized water system		2262
Total Cost		\$ 63144

The installation cost was calculated by assuming a total of 10 hours for the first-time installation and assembly of the design. Furthermore, the total cost estimate for manual labour hours was based on a nominal hourly rate of 200 \$/ hour, which gives a total cost for the installation to be 2000 \$.

The miscellaneous cost of 20 percent was added to the total cost of the mechanical components and pressurized water system to account for new equipment training, and the cost

increase associated with the increase of water usage. Overall, because the total cost for the design was \$63 144 CAD the project was under budget by a margin of 37%.

3.2 Benefit Analysis

In order to determine the various financial benefits associated with the project the new design solution was compared to the current cleaning process. In order to evaluate the total cash flow, the following parameters were considered:

1. Minimum acceptable rate of return (MARR) was set at 4% [15].
2. A two-year rate of return on investment was considered acceptable.
3. A nominal hourly rate of operation is evaluated at \$200/ hour per person.
4. The current cleaning process takes approximately 45 minutes to 1 hour.
5. Approximately 5 people are involved in the current cleaning process.
6. The cleaning process is done after each casting operation and currently occurs on a monthly basis.
7. The total time to clean the propellant mixing bowl using the new design solution is assumed to be 20 minutes.
8. A constant cash flow was assumed for the calculations of present worth analysis.

The cash flow analysis determined that the new design has a cost of \$66.67/month whereas the current cleaning method has a monthly cost of \$1000/month. The results for the cash flow analysis can be found in TABLE V.

TABLE V: CASH FLOW ANALYSIS

Year	Cost (Semi-Automated Propellant Cleaning Device) [A]	Cost (Manually cleaning) [B]	Cash flow differences (B-A)
0	\$ 63144	\$ 0	\$ 63144
1	\$ 800	\$ 12000	\$ 11200
2	\$ 800	\$ 12000	\$ 11200

As shown in TABLE V the present worth of the design cost was \$63 144 CAD and the uniform annual benefit was \$11 200. The present worth of the benefits was evaluated by using a compound interest table with MARR 4% at number of years equal to 2. This resulted in a

present worth factor of 1.886 and a total present worth benefit of \$21 124.32. Furthermore, the benefit to cost ratio was calculated to be 0.34. Therefore, based on the 2-year rate of return, the new cleaning method was a financial downgrade from the current cleaning system. The year at which the new cleaning design becomes financially viable is after 7 years. The tabulated results of the benefit-cost ratio are shown below.

TABLE VI: BENEFIT TO COST RATIO

Year (n)	Present Worth Factor (P/A)	Uniform Annual Benefit [\$]	Present Worth of Cost [\$]	Ratio (Benefit /Cost)
2	1.886	21124.32	63144	0.34
3	2.775	31081.12	63144	0.49
4	3.630	40654.88	63144	0.64
5	4.452	49860.16	63144	0.79
6	5.242	58711.52	63144	0.93
7	6.002	67223.52	63144	1.06

Although the current cleaning solution is the smarter choice financially, the main concern from the client was the safety increase from a new design solution. Furthermore, because the new design solution is under the total budget, it was deemed successful in the benefit-cost ratio.

4.0 Risk Analysis

The risk analysis is composed of a general risk analysis and FMEA (Failure Mode and Effect Analysis). The purpose of the risk analysis was to identify any potential failures through the current design methods and to provide mitigation tactics for these failure methods [16]. The general risk analysis background and identification can be found in Appendix K: General Risk Analysis.

Therefore, this section focuses on anticipating the potential failure modes with the new design by using the FMEA approach. The greatest risks to the new design solution were identified to be the wear of the Teflon coating, the maintenance of the shaft, and the application of lubrication on the toggle clamps. However, all the greatest risks associated with the design could be resolved with routine maintenance performed by Magellan Aerospace.

FMEA was performed on the entire assembly and the installation process in order to identify any possible failure modes. The fit, form, and function of each component on the final assembly, and on the installation, procedure was considered [16]. The detailed step-by-step installation procedure is shown in Appendix L.

In order to accurately measure the severity of a failure mode, the severity, frequency and detection rating scale were used to conduct the qualitative analysis. TABLE VII shows the severity rating scale, which is ranked by the impact that a failure mode would have on the client.

TABLE VII: SEVERITY RATING SCALE [16]

	Severity of effect	Ranking
Minor	Unreasonable to expect that the minor nature of this failure would cause any substantial effect on system performance or on a subsequent process or service operation. Customer unlikely to either notice or care about the failure	1

TABLE VII: SEVERITY RATING SCALE [15] (Continued)

Severity of effect		Ranking
Low	Low severity ranking due to nature of failure causing only a slight customer annoyance. Customer will probably notice only a minor degradation of the service performance, or a slight impact on a subsequent action, i.e., some quick, minor rework	2,3
Moderate	Failure causes some customer dissatisfaction. Customer is made uncomfortable or is annoyed by the failure. Customer will experience some very noticeable inconvenience or performance degradation. May cause either delay due to rework or irreversible damage	4,5,6
High	High degree of customer dissatisfaction due to negative impact of the failure such as an inaccurate payroll run, loss of vital data or an inoperable convenience system (i.e., computer crashes). Does not involve safety or noncompliance to government regulations. May cause serious disruption to subsequent processing; may require major rework or loss to customer and/or create significant financial hardship.	7,8
Very high	Failure mode involves serious personal safety hazards, potential for civil litigation or noncompliance with government regulations.	9,10

Furthermore, TABLE VIII shows the frequency rating scale where the probability of failure is ranked from a remote failure to a very high rate of failure.

TABLE VIII: FREQUENCY RATING SCALE [16]

Probability of failure	Ranking	Possible failure rates
Remote: Failure is unlikely. No failures ever associated with almost identical processes	1	<1 in 20,000
Very low: Process is in statistical control. Only isolated failure associated with almost identical processes	2	1 in 20,000
Low: Process is in statistical control. Isolated failures associated with similar processes.	3	1 in 4,000
Moderate: Generally associated with processes like previous processes which have experienced occasional failures, but not in major proportions. Process is in statistical control	4	1 in 1,000
	5	1 in 400
	6	1 in 80
High: Generally associated with processes similar to previous processes that have often failed process is not in statistical control	7	1 in 40
	8	1 in 20
Very high: Failure is almost inevitable	9	1 in 8
	10	1 in 2

TABLE IX shows the rating scale based on the likelihood of detection which is ranked from very high to absolutely no detection.

TABLE IX: DETECTION RATING SCALE [16]

	Likelihood of detection	Ranking
Very high	Current controls will almost certainly prevent the failure (process automatically prevents most failures)	1,2
High	Current controls have a good chance of detecting the failure	3,4
Moderate	Current controls may detect failure	5,6

TABLE IX: DETECTION RATING SCALE [15] (Continued)

Likelihood of detection		Ranking
Low	Current controls have a poor chance of detecting the failure	7,8
Very low	Current controls probably will not detect the failure	9
Absolute certainty of non-detection	Current controls will not or cannot detect the failure	10

In order to avoid any bias in the calculated values for the risk priority number (RPN) which is the product of the severity ranking, frequency ranking and detection ranking, the team performed a brainstorming exercise to identify the final ranking for each procedure.

4.1 Process FMEA

The following TABLE X identifies the operations performed during the installation of the cleaning solution and any failures that could occur during the cleaning cycle. Any potential failure methods or failure causes are identified with each failure mode.

TABLE X: PROCESS FAILURE MODE AND EFFECT ANALYSIS

Operation Description	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Current Control	DET	RPN
First time Installation of the pressurized water system	Water pipe and joint are not properly connected	Leaking joint	2	Operator's inattention	3	Visual	2	12
Installation of the Mechanical components such as (Retaining ring, fasteners, mounting plate, motor and bearing)	Operator's improper installation	Shaft might fall off and damage the shaft, Injury to operators	8	Operator's inattention	3	Visual	1	24
Lifting the assembly by hooking the three eyebolts	Improper lifting damages the side and bottom scrapers	Damaged scraper cannot apply enough force to scrape propellant out	8	Operator's inattention	3	Visual	1	24
Insert assembly into mixer bowl, fix dowel pin and clamp the lid using toggle clamps	Assembly is placed off centre	Misalignment of assembly would provide unbalanced pressure force and effect the shaft integrity	5	Operator's inattention	1	Visual	1	5
	Lid is not clamped properly	Lose control of rotating shaft and the assembly would vibrate to damage the blade and scraper	4	Inadequate installation	1	Visual	2	8
Assemble hydraulic power system	Incorrect installation of hydraulic intake and outtake for the hydraulic motor	The shaft rotates opposite direction to the direction intended	3	Operator's inattention or improper set up	4	Visual	1	12
	Operator could not properly connect hydraulic power system with hydraulic motor	incorrect installation would cause insufficient hydraulic power	4	Operator's inattention	1	Visual	2	8

TABLE X: PROCESS FAILURE MODE AND EFFECT ANALYSIS (Continued)

Operation Description	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Current Control	DET	RPN
Pressurized water system connect to swivel joint through funnel	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cleaning process phase I (pressurized water system open)	Pressurized water cannot provide enough pressure due to head loss or friction losses	Insufficient pressurized water to flash off the propellant residuals	3	Improper set up	1	Preventative maintenance	4	12
Cleaning process phase II (pressurized water system close)	Thick propellant might cause extra force required for scraper to push the propellant	Large deflection of rubber would cause insufficient force applied to propellant	4	Bottom scraper capability	4	Visual	1	16
Take out and clean the assembly, disassemble all the components	Residual propellant left on the scraper would drop into mixer bowl	Require human manually scrape the residual propellant and extra labour hour	3	Residual propellant left after casting	7	Visual	1	<u>21</u>
	Residual water could not be drained through funnel	require human manually clean the mixer bowl	3	The mixer bowl can not be cleaned completely	6	Visual	1	18
Store lid assembly, mechanical scraping system at clean, dry, noncorrosive atmosphere	Components might get corrosion	Corrosive components cause inner or our leakage	1	Improper storage	2	Visual	1	2

4.2 Recommended Action for Cleaning Procedure

From the operation process analysis, the installation and lifting of the entire assembly both before and after the cleaning process were identified to have the highest RPN values (RPN values greater than 20). This was due to the risk of an operator not paying attention during the installation process and the uncertainty surrounding the amount of residual propellant that will be left in the mixing bowl after the casting process. The recommended actions for these highest risk procedures are shown below in TABLE XI. Furthermore, the recommended action for the manual process' involved in the installation process are included for the operator's knowledge.

TABLE XI: RECOMMENDED ACTION FOR OPERATION PROCESS

RPN	Operation Procedure	Actions Recommended
<u>24</u>	Installation of the Mechanical components such as (Retaining ring, fasteners, mounting plate, motor and bearing)	Ensure all the nuts and bolts are fastened together before and after cleaning operation. Ensure there is no damage on the location where the retaining ring sits on the shaft.
<u>24</u>	Lifting the assembly by hooking the three eyebolts	Ensure the hooks are latched properly onto the eyebolt
<u>21</u>	Take out and clean the assembly, disassemble all the components	Operator stand on a high stage and manually clean the residual propellant and water by using long-stick mop or squeegee
<u>12</u>	First time Installation of the pressurized water system	Do a leak test and ensure there is no leaking.
<u>12</u>	Assemble hydraulic power system	Ensure the system is connected properly or provide a user guide for operators or proper training modules. / Test the entire assembly to ensure there is enough pressure to flash off the propellant residuals

4.3 Assembly Components FMEA

The FMEA conducted for each of the assembly components is shown below in TABLE XII

TABLE XII: DESIGN COMPONENT FAILURE MODE AND EFFECT ANALYSIS

Design system	Component	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Current Control	DET	RPN
Teflon Coating Application	Teflon coating	surface imperfections or loose adhesion of Teflon coating	The forces required to shear the propellant will increase	3	Long time cycles cause Teflon Degradation	4	Preventative maintenance	1	12
Hydraulic power system	Hydraulic power system	Cavitation or aeration	Damage pump, loose connections or system leak	1	Improper set up	3	Hearing abnormal noise	1	3
		Operator's improper installation or mismatched components	Motor might run over its maximum drive speed	2	Operator's inattention	2	Visual	1	4
Lid components	Lid with rotating eyebolts, dowel pins and toggle clamps	The movable parts and threads of toggle clamps get stuck	The toggle clamps cannot tighten the lid properly	3	Insufficient lubrication of lightweight oil	1	Preventative maintenance	2	6
	Locating bearing	Flaking or skewing	Shaft might not operate properly	4	Improper lubrication	2	Hearing abnormal noise	1	8
	Couplers	Split hub, rupture or crack of flexible elements	Shaft might not rotate properly	3	Excessive torque loading or coupling misalignment	2	Hearing noise	1	3
	Retaining ring	Overload on groove cause retaining ring deformation	Loose control to hold shaft in place where the shaft will fall off	3	Underestimate groove load	1	Visual	1	3

TABLE XII: DESIGN COMPONENT FAILURE MODE AND EFFECT ANALYSIS (Continued)

Design system	Component	Potential Failure Mode	Potential Effect	SEV	Potential Causes	OCC	Current Control	DET	RPN
Pressurized water system	Water pipe	Corrosion or fatigue	Pressure fluctuation cause low pressure to flush the propellant	1	Chemical reaction	1	Visual	1	1
Pressurized water system	Water pipe	Corrosion or fatigue	Pressure fluctuation cause low pressure to flush the propellant	1	Chemical reaction	1	Visual	1	1
Pressurized water system	Water pipe	Pipe wall rupture	Pipe rupture or tear leads to an open wall that might decrease the pressure	1	Natural failure of Ductile material	1	Visual	1	1
Mechanical scraping system	Shaft	Fatigue or torsional fatigue	Long-time cyclical stresses or loose coupling fit could lead to shaft fatigue	3	Long-time use	3	Visual	2	18
	Side blades	Large displacement of rubber scraper	Thick propellant remaining on the side surface leads to extra force applied to rubber	4	Extra propellant left	2	Visual	1	8
	Bottom scraper	Large displacement of Rubber scraper	Thick residual propellant left on the bottom surface	4	Extra propellant left	2	Visual	1	8
Below the mixing bowl	Swivel joint	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Funnel	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

4.4 Recommended Action for Assembly Components

In the assembly component risk analysis, the top two failure modes occurred with the mechanical scraping components at an RPN above 10. Repeated use of the cleaning system could cause cyclical stress on the shaft and the scrapers. Thus, resulting in the strength of the components to decrease. This includes the risk of the Teflon coating needing to be reapplied periodically. Therefore, in order to mitigate the risk of material and components from cyclic loading or material cracking regular maintenance should be performed by Magellan Aerospace. The recommended actions are shown in the table below.

TABLE XIII: RECOMMENDED ACTION FOR DESIGN COMPONENTS

RPN	Operation Procedure	Actions Recommended
18	Shaft	Shaft repair service
12	Teflon coating	Repair and reapply [17]
6	Toggle clamps	Regular Light-oil lubrications
	Regular Maintenance: <ul style="list-style-type: none">• Regular inspection on all the components• Check and fasten hardware• Proper lubrication on bearing and couplers• Cleaning and proper drying, storing assembly	

5.0 Design Summary and Recommendations:

The design components of the final design were considered and compared to the technical specifications to confirm that all the client’s needs were met. The only need that was not met was that the noise level of the design exceeded the threshold for hearing damage of a human. Therefore, it is recommended that any operators in the vicinity require hearing protection. However, there are some needs that will not be able to be confirmed until the product is tested. Therefore, any technical specifications that cannot be verified until tested will be denoted with an asterisk. The results are tabulated below.

TABLE XIV: FINAL DESIGN COMPARISON FOR NEEDS AND SPECIFICATION

Number	Needs Met	Metrics	Units	Specifications	
				Design Solution	Ideal/Marginal Pass
1	1,12	Quality Inspection	pass/fail	*	*
2	2,3,4,5,13	Safety/Risks	pass/fail	Pass	Marginal
3	2	Noise Level	db.	78	<u>Fail</u>
4	15	Operator Movement	m	>20 m	Marginal
5	6,9	Size	ft^3	152 ft^3	Marginal
6	10	Life Cycle	cycles	Infinite	Ideal
7	7,10	Stress on equipment	MPa	3 F.O.S	Ideal
8	11	Process Time	minutes	*	*
9	8	Easy Interface	subj	Requires Setup	Marginal
10	5,13	Temperature	deg F	180 F	Ideal
11	16	Waste Produced	lb	*	*
12	14	Cost	\$ CAD	63,144	Ideal

There are several design aspects that were not considered in this project due to the limited scope. Therefore, there are some recommendations that need to be considered before producing the cleaning system for its intended purpose. The largest constraint of the project was that while results were simulated, it is recommended that intense physical testing take place to confirm the simulated results. This will accurately measure the cycle time of cleaning, and the effectiveness of removing the propellant. Furthermore, the testing would determine how much water would be required and the total amount of waste produced from one cleaning cycle.

Another aspect that was considered out of the scope was the application of the Teflon coating. While the Teflon coating significantly lowers the amount of shear force required to clean the surface of the propellant mixing bowl, the coating may need to be reapplied after applying significant forces or excessive use. The life cycle of an effective Teflon coating is unknown and further research and testing is recommended in order to gauge an accurate picture of how often a recoat would need to be applied. Furthermore, it was assumed that the Teflon and any materials involved in the design would not interfere with the rocket propellant chemical composition based on company experience. The extent of this knowledge was not passed onto the team and thus it is not a guarantee that any or all of the components, specifically the Teflon coating, will not affect the integrity of the propellant during the mixing and/or casting phase.

Lastly, other design concepts were generated but determined to not be the best design concept done by screening and scoring methods performed by the team. However, one of the identified design concepts could create a final design that is better suited for the application. The total list of design concepts can be found in

6.0 Conclusion

The primary goal of the project was to design a new safe and efficient propellant cleaning process to clean the residual propellant from the mixing bowl. The current cleaning process required an operator to climb inside the mixing bowl to manually scrape down and wipe down the propellant from the side and bottom of the mixing bowl. Furthermore, the current cleaning process is not pleasant as the bowl is hot, slippery, and is considered a confined space [2].

The final design was developed using an iterative and incremental approach by dividing the project into three distinct phases. The first phase included identifying the customer needs and the required engineering metrics to meet those needs. This included research on the root cause of the problem which was done using the problem-solving method called DMAIC (an acronym for Define, Measure, Analyze, Improve and Control). The second phase of the project included generating concepts and ranking these concepts based on screening and scoring metrics that considered both quantitative and qualitative analysis. Finally, the third phase included the final detailed design phase, where the concept selected in the concept development phase was further refined to meet the customer needs and specifications. The testing and evaluation phase of the iterative and incremental development was not included in the scope of the project.

The final design solution included a pressurized water system and high strength anti-static neoprene rubber scrapers to clean the sides and bottom of the propellant mixing bowl. This new design uses a hydraulic system to provide power to the system. The final design is a semi-automated system where the full assembly gets clamped onto the mixing bowl after being placed in the bowl by an overhead crane lift. The pressurized water system and hydraulic power lines are then connected to their respective fluid lines. Furthermore, all the designed components were analyzed for stresses and loads. The most critical component was the shaft. The final shaft design demonstrated a safety factor of 3 while considering different modes of failure such as static, fatigue and deflection, hence providing a safe and effective design.

A detailed cost-benefit analysis determined the total cost of the budget to \$63 144 CAD, which is underbudget by 37%. Furthermore, a pay back period of 7 years was identified when compared to the current process.

A risk analysis was conducted and determined the highest risks to be the Teflon coating requiring reapplication, the toggle clamps requiring lubrication, and the risk of fracking or cyclic loading on the shaft. To mitigate the risks associated with the project the operators will have to receive training on how to perform routine checkups on cleaning equipment.

To conclude, the final design is a success because the design solution eliminates the need for operator to climb inside the mixing bowl and provides reduction in operating time and cost while increasing the total safety for the operators. The design meets all of the currently verifiable target specifications, except for the noise level metric for which the team recommends a requirement for operators to wear hearing protection while operating the cleaning equipment. Furthermore, it is recommended that the final design go through a prototype phase and receive physical testing in a controlled environment before being installed permanently. All of the expected project deliverables are provided in this report that included preliminary engineering drawings of the important design components with detailed bill of materials as mentioned in Appendix M - Engineering Drawings. Therefore, the final design solution is considered acceptable and a success.

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Appendix A: Concept Development

This section outlines the various design concepts developed to clean the rocket propellant mixing bowl. This includes general material consideration, the design solution working principle, any waste materials or consumables, and the amount and type of power required for the cleaning process. Furthermore, all designs use automation or novel techniques that eliminate the need for the operator to climb into the mixing bowl and consider all relevant explosive safety issues. The concept development process was performed by using both internal research ideas from Magellan and researching current industry solutions. The concepts were generated during a brainstorming session where every unique possibility was considered, using brainstorming tools known as rapid idea generation and round table idea generation. After this initial round of brainstorming, the concepts were tasked to team members to perform individual research on each idea. After performing research on existing technology, through patent checks and current industry leaders, the individual team members created further concept designs based off the most optimal working principles and presented the new concepts to the team. These optimal working principles were determined based off similar designs from the Indian Space Research Organization [18] and other aerospace relevant parts, such as, current cleaning processes for jet engines large, industrial boilers, and large propellant mixing bowls [18].

Through concept generation eleven different clean methods were developed with a total of 14 unique design concepts. The concept development map from brainstorming can be seen in Figure 24.

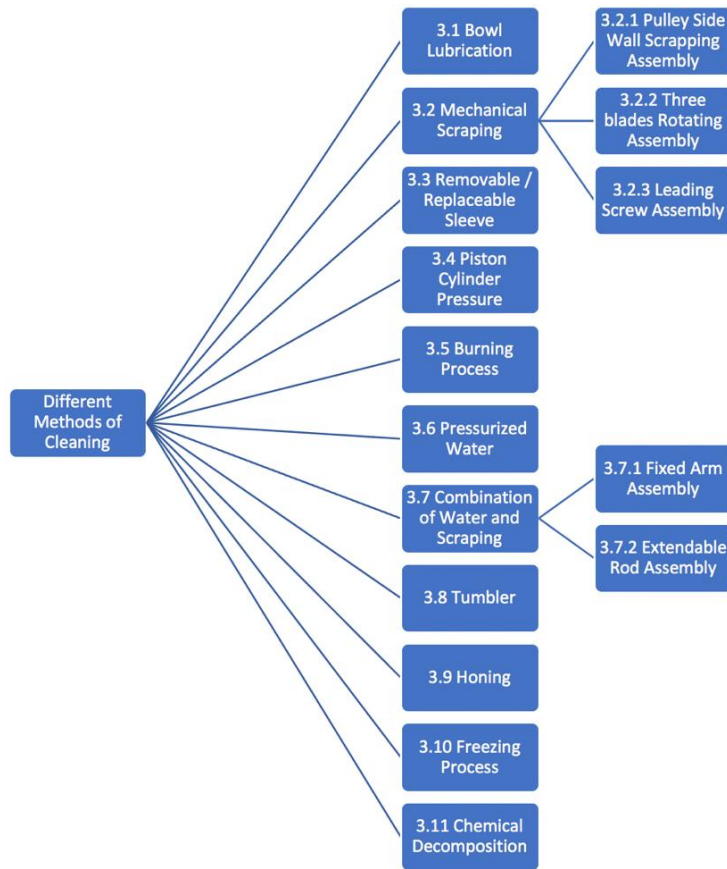


Figure 24: Different Methods for Cleaning the Propellant Mixing Bow

A.1 Bowl Lubrication

One of the design approaches taken by the team was to address the root cause of the problem and attempt to decrease the amount of propellant waste remaining in the bowl after casting. This would cause more propellant to be removed during casting and thus reduce the amount of residual propellant needing to be cleaned from the bowl. In addition, this would reduce the amount of propellant waste that is later burned. With less residual propellant the cleaning process could be significantly improved and would require less shear force to remove the propellant. Thus, this design solution could be used in conjunction with another design solution to improve the overall performance and cleaning process.

The bowl lubrication could be achieved by applying a coating or lubricant on the inside of the surface of the mixing bowl. However, the coating/lubrication needs to not change the chemical composition of the propellant. Therefore, various coatings and lubricants were

researched. Teflon is an example of a widely used material in the aerospace industry due to its highly advantageous material properties. Some of the key attributes for Teflon include its high chemical resistance, its low coefficient of friction, its hydrophobicity (repels water) and its high temperature resistance [19]. Another example of a coating that could be applied is a polyimide graphite composite. An example of this material is TECASINT 2021™ which has good slide and wear properties, high thermal and mechanical properties and high impact strength [20]. The high impact strength is important because this concept would have to be paired with another design solution that could potentially cause wear on the coating.

A.2 Mechanical Scraping

Mechanical scraping is a working principle that was developed by the team where a power drive, whether manual or automatic, will deliver rotational power to a device that removes the propellant from the bowl. The power input could be either an electric motor, pneumatic system, hydraulic system, or manual mechanisms such as a crank arm. From this working principle three separate designs were developed that will later be compared in the screening and design selection of the report.

A.2.1 Pulley Side Wall Scraping Assembly

The first mechanical scraping concept design is a pulley system that mimics the existing Magellan Aerospace cleaning procedures through automation [2]. The whole assembly consists of a cover plate, a cleaning pulley, an input pulley, CNC parts, a hydraulic or pneumatic power input system and a vertical shaft. The power is transmitted from the input along a input pulley to an intermediate shaft connected to the cleaning pulley. The cleaning pulley rotates a vertical shaft connected to a cover plate with silicone strips on the side that remove the propellant and curved silicone strips on the bottom to funnel the propellant towards the ball valve discharge hole. The cover plate would most likely be made of the same stainless-steel grade as the bowl to maintain its good corrosion resistance properties. Furthermore, for the sake of this design report the power input system will not be designed until detailed design is performed. In addition to the mechanical scraping mechanism a water and soap solution would be used to clean the surface of the bowl once the bulk of the propellant waste is removed. Lastly, due to

the unique shape and size of the bowl, most parts included in this design would be fabricated using a CNC machine. A sketch and model of this concept are shown below in Figure 5:

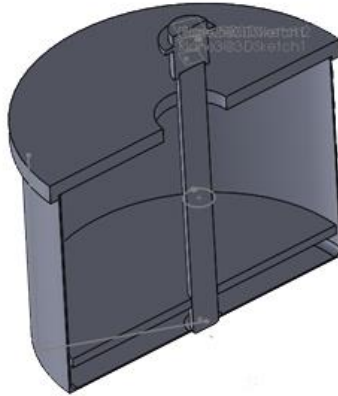


Figure 25: Pulley Side Wall Scraping

A.2.2 Three Blades Rotating Assembly

The second design concept in mechanical scraping utilizes three rotating blades, with each blade covering a section of the inside surface of the bowl. The three blades would be designed such that the edges of the blade lift the propellant off the inside surface of the bowl. This would involve rounding the blades to provide forces normal to the bowl surface, and a sharp leading edge to contact the surface of the bowl (“underneath” the propellant). The blades would also be wrapped in a non-sparking rubber material. Furthermore, the blade that runs along the bottom of the bowl would have a sharp edge both on the side of the bowl and along the bottom surface. The edge of the blade along the bottom of the bowl would be bigger to accommodate the increase of propellant waste as it is scraped from the top layers. The bottom blade would also have geometry to match the bottom fillet radius of the bowl.

The design reasoning behind using three blades is to dynamically balance the shaft as the assembly rotates. This will lead to less vibration and an increase in design life. A model for this concept is shown below in Figure 26.

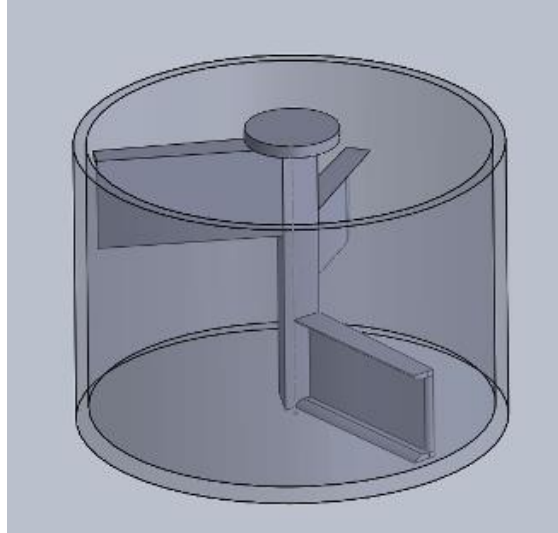


Figure 26: Three Blades Rotating Assembly

A.2.3 Leading Screw Assembly

Another design solution that works of the principle of mechanically scraping the propellant off the inside surface of the bowl is one where the arms spin along a leading screw that can be powered either manually or automatically. The arms of this design would be spring loaded so that they maintain contact with the surface of the bowl throughout the entire cleaning process. This design would work in cycles and would have six different tool ends adjusted after each cycle. The order of the tool ends is shown in the following list:

1. A scooping tool that scoops most of the propellant off the sides of the bowl.
2. A scraping tool that would scrap off the remaining propellant leaving just a thin layer of propellant that slightly discolours the surface of the bowl.
3. Next, the bottom of the bowl would be cleaned using a curved scooping tool that pushes the waste propellant towards the ball valve discharge hole. This tool would sit on the bottom of the leading screw and rotate for a set time.
4. The fourth tool would scrap the bottom of the bowl to ensure there is no propellant left in the corner radius and collect any propellant left after the scooping tool.
5. The fifth tool would then be a mop tool that sprays soap and water while using a squeegee like tool end to clean the surface of the bowl.
6. Finally, the bottom of the bowl would also be cleaned with a mop tool.

The design would be made of stainless steel and the tool ends would be from non-static polymer materials. An important design consideration for this technique is the added process time required for using multiple tool configurations. However, the required time would be determined during the testing of the process and is therefore outside the scope of this project. Furthermore, the required power for the operator to crank the mechanical mechanism, or the design of the pneumatic, hydraulic, or electrical power input, will be designed during the next phase of the project. An example of this design is shown below in Figure 27.



Figure 27: Leading Screw Assembly

A.3 Removable/Replaceable Sleeve

Another design solution is to insert a removable sleeve that fits on the inside of the mixing bowl. This would eliminate the need for the mixing bowl to be substantially cleaned because the sleeve could be removed and cleaned using alternative methods. The sleeve could be designed out of the same stainless-steel grade as the bowl or out of a polymer material, such as Teflon. The method for cleaning the sleeve is still open ended and could be used in conjunction with another design concept. An example of a removable sleeve is shown below in Figure 28.

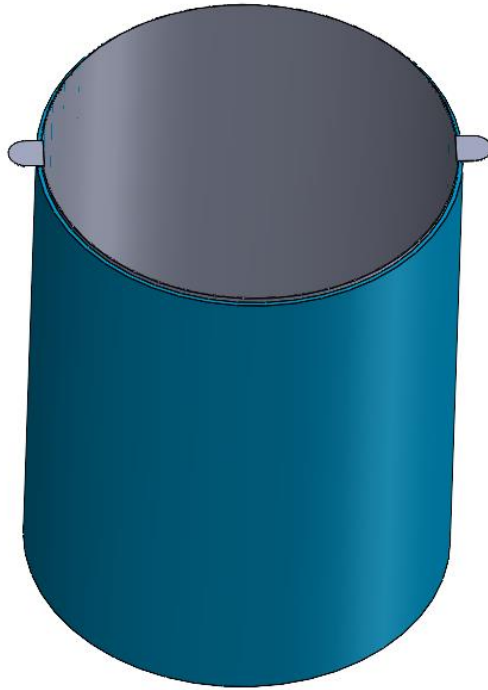


Figure 28: Removable/ Replaceable sleeve

A.4 Piston Cylinder Pressure

A piston cylinder using pressure as the main cleaning method was also considered for a design solution. The piston would have to be rigged to the top of the bowl, while ensuring perfect surface contact on the inside diameter of the bowl. This could be achieved by using a flexible material on the rim of the piston so that the contact between the surface of the bowl and the piston would have the elastic forces of the material creating a suction like force. The piston would also have to be made of a material that was non-sparking. As the piston would slowly push down on the inside of the bowl, the force and pressure would push the excess propellant out of the bowl through the opening in the bottom of the bowl. It is important to note that the pressure forces would have to be greater than the pressure exerted when the propellant is casted. This is because the pressure forces must shear the excess propellant off the inside surface of the bowl. Furthermore, in order to clean the bottom of the bowl, the piston edge would have to have an adjustable diameter. This would allow the bottom surface of the bowl to be cleaned after all the side walls have been cleaned. The adjustable diameter would also eliminate any concerns regarding residual propellant being dragged up the sides of the bowl.

when removing the piston head. An example of this working principle can be shown below in Figure 29.

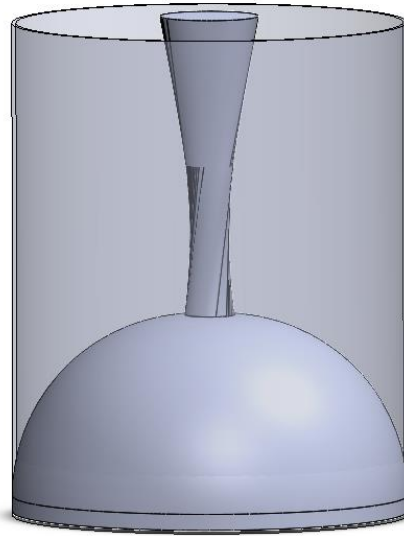


Figure 29: Piston Cylinder Pressure

A.5 Burning Process

Another method considered to clean the mixing bowl was to burn off the excess propellant. The burning process could be performed in a controlled environment outside of the explosive class 1.3 designation building. After burning the excess propellant off, other techniques would have to be explored on how to clean the soot off the inside surface of the bowl. For example, the propellant could be burned off and then the bowl could be run through a pressurized water system that would clean and sanitize the bowl for the next propellant mixing batch.

A.6 Pressurized Water:

Another method considered to clean the mixing bowl was to use pressurized water with multiple nozzles at various angles as shown in Figure 30 (b). This nozzle mechanism uses the fluid to rotate a turbine connected to a gear drive system. The drive system then rotates the hub around the central shaft [21], where a greater liquid pressure produces faster rotational motion around the shaft. The design is intended to work while the mixing bowl is on the cleaning stand. The shaft will be rotated through a motor, hydraulic system or pneumatic system and the water will run through a compressor, pressurizing the water with enough force

to both rotate the nozzle mechanisms and shear the propellant off the bowl. Furthermore, a funnel with negative pressure will be attached to the ball valve hole, as shown in Figure 30 (a), to remove the mixture of propellant residuals and water and guide it in the waste container. The method of using pressurized water was based on external research done for cleaning procedures of boiler tanks and reactors.

Although most designs consider using water to clean the propellant this design concept uses just the shear force of the water to clean the bowl. Furthermore, in order to ensure that the bowl does not fill up with water and prevent the water spray from contacting the bowl surface, the system can be run in cycles (like a dishwasher) to allow water and propellant to sufficiently drain. The timing of these cycles would be determined through the testing process.

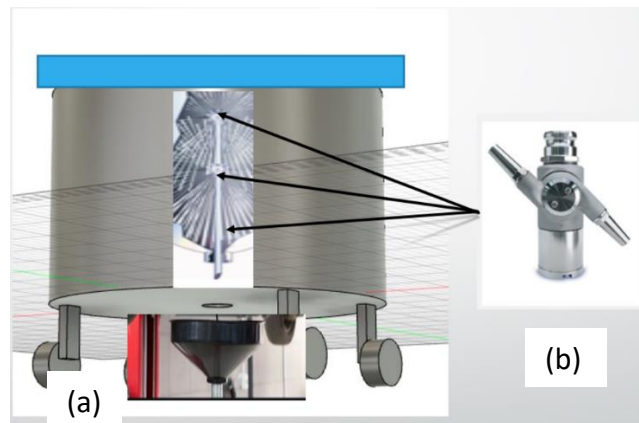


Figure 30: Pressurized Water Assembly (a) Using pressurized water to clean the mixing bowl with the funnel at the bottom to collect the propellant residual waste, (b) Spraying Nozzle Mechanism

A.7 Combination of Water and Scraping:

Another method considered to clean the mixing bowl consisted of combining concepts from mechanical scraping and pressurized water. By combining these two working principles the cleaning process gains numerous benefits such as the pressurized water acting as a coolant for the rotating tool scraping off the propellant. Furthermore, with both the pressurized water and the tool ends removing the propellant material will lead to decrease in the cleaning process time. In order to sufficiently represent the variety of design ideas under this working principle, two design concepts were developed are outlined below.

A.7.1 Fixed Arm Assembly:

The first idea in the category of combining pressurized water with mechanical scraping consisted of a frame with hollow tubes as shown in Figure 31, where pressurized water will flow inside the tubes and out the small holes located along the vertical tubes. The entire assembly is rotated around the central shaft so that the pressurized water can reach the entire inside surface of the bowl. Furthermore, a curved scraping tool is located along the bottom of the bowl that pushes the waste towards the exit hole. Similarly, there is two scraping tools on the sides of the assembly that ensure any propellant missed by the water is removed.

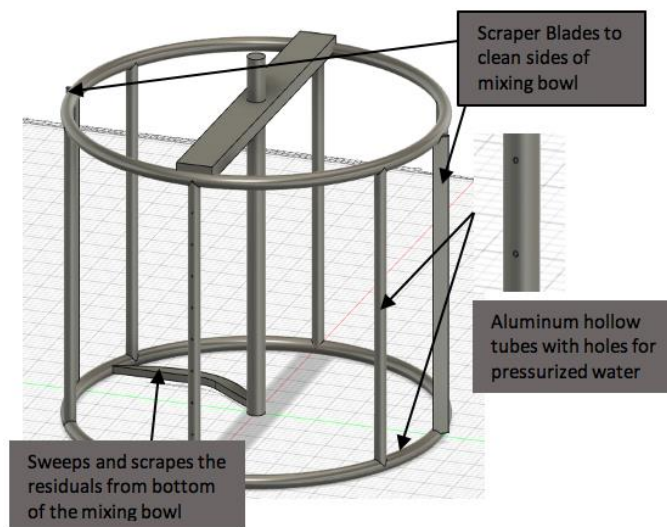


Figure 31: Combination of Water and Scraping (Fixed Arm)

A.7.2 Extendable Rod Assembly:

The second concept idea that combines pressurized water and scraping together involves an input motor that is installed on the top of a rotating shaft that rotates the whole assembly. A bearing is installed between the shaft and lid so that the lid will be at a static state to cover the spilled water. Two water outlets are installed on the shaft for spraying pressurized water and a soap solution in order to clean the surface of the bowl. Two extendable rods are installed on the shaft to scrap the side walls and the bottom of the bowl. In order to clean all surfaces the shafts can rotate from 0° to 90° . The two scrapers are covered by a rubber material to ensure non-sparking condition. As shown in Figure 32, the entire assembly can be moved up

and down to ensure complete inside surface coverage of the bowl. Furthermore, this design solution could be programmed in a fully automated solution.

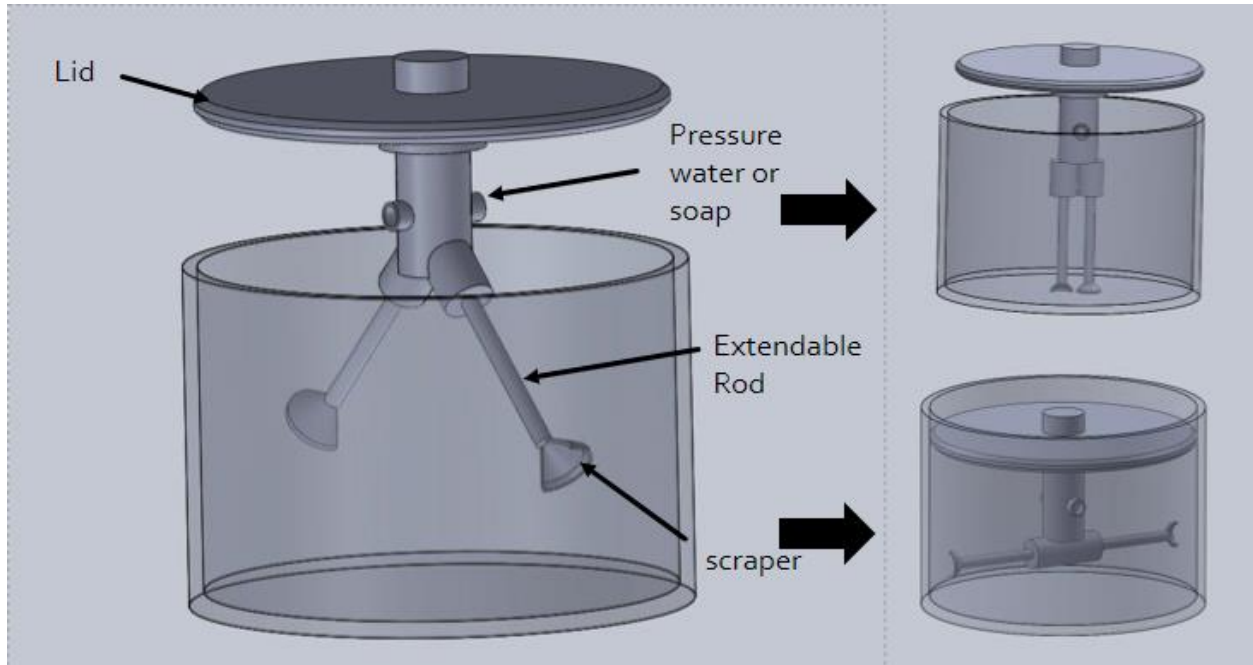


Figure 32: Combination of pressure water and scraping (Extendable Rod)

A.8 Tumbler

Using a tumbler is a design solution that is widely used in industry to remove any sharp edges on aluminum parts or to clean off rust from steel parts. In order to clean the residual propellant, the mixing bowl would require some modifications. As shown in Figure 33 below, the propellant mixing bowl would be placed on the vibratory power source and the media (stones and aluminum) would be placed inside the mixing bowl. The abrasive material inside the mixing bowl removes the propellant stuck to the inside surface. After cleaning the media and waste would be removed through the ball valve discharge hole.

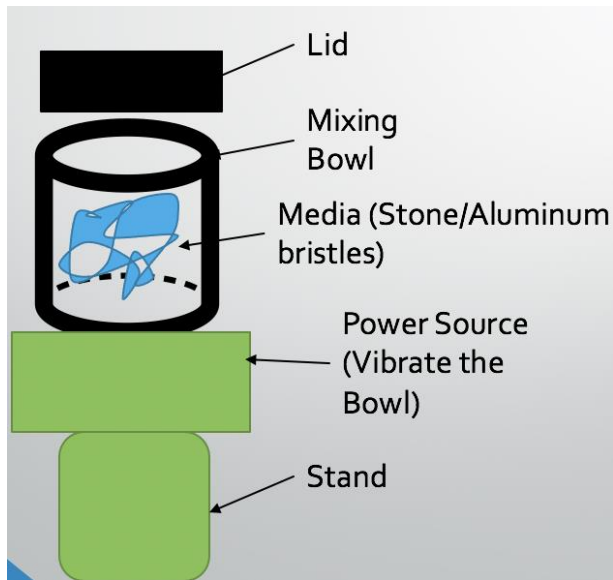


Figure 33: Using tumbler to clean the propellant residuals

A.9 Honing

Honing was another method considered for the cleaning process as it is also widely used in industry to clean steel surfaces. As shown in Figure 34 below, this concept would involve a CNC vertical honing machine used to clean the residual propellant from the mixing bowl. After removing all the propellant waste, the inside surface of the bowl would have to be cleaned using pressurized water. Similar to some previous designs, this design could be used in conjunction as a preliminary step in the cleaning process.

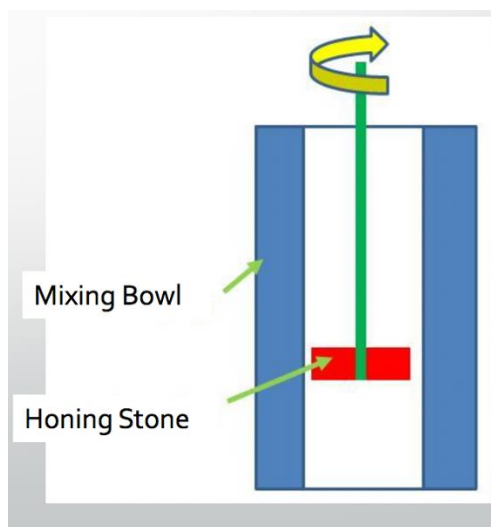


Figure 34: Design concept Honing

A.10 Freezing Process

This idea behind this concept was to change the phase of the propellant by cooling it down to freezing temperatures. When starting the cleaning process, the temperature of the propellant is at 120°F and has a high viscosity ranged from 400,000 to 800,000 cP [2]. Therefore, in order to easily break or remove the propellant, the phase of propellant would be transitioned to a solid phase by cooling it. This would allow the solid propellant to be easily broken off the surface of the bowl using a hard tool.

A.11 Chemical Decomposition

The Chemical Decomposition method was generated to try and decrease the total force required to remove the propellant. This would involve applying a chemical solution to dissolve the propellant. Therefore, this process was based off a cleaning method for chemically cleaning an aluminium alloy propellant mixing bowl. The composition of the cleaning solution is shown below [22]:

TABLE XV: CHEMICAL COMPOSITION

Chemicals	Percentage (%)
Sodium Silicate	10
Sodium Tetrafluoroborate	15
Sodium Molybdate	0.5
Water	88

The same aqueous solution can be applied to clean a stainless-steel mixing bowl in order to soften the residual propellant and decrease the shear forces required.

Appendix B: Concept Analysis and Selection

This section provides a detailed step by step engineering process of refining the design concepts by first eliminating designs that are impractical or not feasible. The designs will then be screened through the customer needs to determine which designs should be continued to the scoring phase. After screening the designs, the remaining designs will then be given a final score to determine which designs to continue with in to phase III of the project, that is detailed design. Material selection and costs associated with the design concepts are mentioned but not considered crucial to the design selection process because budget is a low priority need.

B.1 Design Concept Exclusions

The following five concept solutions were excluded from the concept screening process because they were deemed not feasible for a variety of reasons. The concepts excluded are as follows:

1. **Burning (3.5)** - After initial research performed on this potential design concept it was determined to be not feasible. This is due to the high burning temperature of the rocket propellant that would damage the integrity of the mixing bowl. Furthermore, the combustion process of the rocket propellant would be a safety hazard.
2. **Tumbler (3.8)** - Some of the disadvantages identified with this method was that it will provide excess waste, from the media, and that there is a high risk for the propellant to ignite from the constant friction with the media. Furthermore, the media also has the potential to affect the integrity of the stainless-steel mixing bowl.
3. **Honing (3.9)** - There were some disadvantages associated with this design concept such as the integrity of the mixing bowl from repeated contact with the honing stone. Furthermore, this process could generate heat (from the impact) that could potentially ignite the propellant, causing catastrophic events.
4. **Freezing (3.10)** – This technique was deemed infeasible because in order to cause a phase transition (from liquid to solid) the propellant would have to be cooled down below negative 50°C. This would cost a significant amount of money to chill the entire bowl below negative 50°C and would only be possible in Winnipeg during the cold winter months.

5. **Chemical Decomposition (3.11)** – After researched was discussed with the client and Magellan’s chemist, this design solution was not desired because of the high cost associated with the solution. Furthermore, it was determined that a soap and water solution was suitable enough for the cleaning process.

Therefore, none of these five concepts will be considered for the final design solution or be further developed in the detailed design phase of the project.

B.2 Concept Screening

In order to narrow down the design concepts a qualitative analysis was done for the remaining of the design concept ideas that are not mentioned in section B.1 Design Concept Exclusions. Each design was compared with the technology used by Indian Space Research Organisation (ISRO) to clean their propellant bowl because this technology is semi automated and performs a similar operation to what Magellan currently desires for the cleaning solution. The matrix shown below gives score in terms of “0”, “+”, “-” by comparing the design concepts with ISRO current cleaning solution. The proposed design was assigned a “0” if the concept design provides similar customer requirement, a “-” was assigned if the concept design provides worse results based on customer requirements and “+” if it was better than the ISRO for the specific criterion. The net value was than calculated by adding all the “+” and subtracting all the “-”. Results with a net value above zero will advance to the next stage of concept scoring. The screening metrics can be found below in TABLE XVI.

TABLE XVI: CONCEPT SCREENING

		Bowl Lubrication	Mechanical Scraping (Pulley Side Wall Scraping)	Mechanical Scraping (Three blades Rotating Assembly)	Mechanical Scraping (Leading Screw Assembly)	Removable/Replaceable Sleeve	Piston Cylinder Pressure	Pressurized water	Combination of water and scraping (Fixed Arm Assembly)	Combination of water and scraping (Extendable Rod Assembly)	ISRO current cleaning Solution
Needs Number	Customer Requirements	3.1	3.2.1	3.2.2	3.2.3	3.3	3.4	3.6	3.7.1	3.7.2	Ref
1	Clean entire inside surface of the mixing bowl	-	0	0	0	-	-	-	0	0	0
2	Safe for operators	0	0	0	0	-	0	0	0	0	0
3	Eliminate operator climbing into the bowl	0	0	0	0	0	0	0	0	0	0
4	Safe transportation of hazardous wastes	0	0	0	0	0	0	0	0	0	0
5	Not generate heat to point of creating spark or explosion	0	0	0	0	-	0	0	0	0	0
6	Work for 420-gallon Baker-Perkins vertical mixer bowl	0	0	0	0	0	0	0	0	0	0
7	Keep the integrity of the mixing bowl	+	0	0	0	-	0	0	0	0	0
8	Easy and intuitive to operate	+	-	0	-	0	+	0	-	-	0

TABLE XVI: CONCEPT SCREENING (Continued)

		Bowl Lubrication	Mechanical Scraping (Pulley Side Wall Scraping)	Mechanical Scraping (Three blades Rotating Assembly)	Mechanical Scraping (Leading Screw Assembly)	Removable/Replaceable Sleeve	Piston Cylinder Pressure	Pressurized water	Combination of water and scraping (Fixed Arm Assembly)	Combination of water and scraping (Extendable Rod Assembly)	ISRO current cleaning Solution
Needs Number	Customer Requirements	3.1	3.2.1	3.2.2	3.2.3	3.3	3.4	3.6	3.7.1	3.7.2	Ref
9	Retrofittable in the current processing plant	0	0	0	0	0	0	0	0	0	0
10	Long-life cycle	0	0	0	0	-	+	0	0	0	0
11	Decrease cleaning process time	+	+	+	0	-	+	+	+	+	0
12	Repeatable results	0	-	-	-	-	-	-	0	+	0
13	Work in warm environmental temperatures in the building	0	0	0	0	0	0	0	0	0	0
14	Under budget	+	0	0	+	+	+	0	0	0	0
15	Efficiently minimize operator involvement	-	0	0	0	-	+	0	0	+	0
16	Efficiently minimize the use of consumables	0	0	0	0	-	0	0	0	0	0
	+	4	1	1	1	1	5	1	1	3	
	0	10	13	14	13	6	9	13	14	12	16
	-	2	2	1	2	9	2	2	1	1	
	NET	2	-1	0	-1	-8	3	-1	0	2	
	RANK	2	8	4	7	13	1	6	5	3	
	CONTINUE?	YES	NO	NO	NO	NO	YES	NO	NO	YES	

Based on the concept screening matrix the design concepts that will continue in the design selection process, include concept design 3.1, design concept 3.4, and design concept 3.72. Furthermore, while design concepts 3.2.2 and concept 3.7.1 had an equivalent score to the ISRO process, these processes were not considered to pass because the level of expectation for the new design process is higher than the solution currently being used by ISRO. This is because the reference for the screening did not yield the highest scoring. Therefore, any design equivalent to the reference could simply be replaced by the current existing technology, and a design solution would not need to be developed.

B.3 Concept Selection

This section describes the quantitative analysis for the design concepts that passed through the concept screening. Specific criteria were weighted using a systematic approach to create a weighting matrix that will be used to give the design concepts a score.

B.3.1 Criteria Weighting

In order to create a weighting score for each criterion, a weighted matrix was created as shown in Table VI below. The criteria considered is the customer needs described in Section 2.0. Furthermore, each of the customer needs were compared directly with one another and a quantitative priority for each need was categorized. Based on the comparison between each individual customer need, a weighting was calculated as a percentage of the total customer needs. The weighted results of the customer needs comparison are shown below in Table V.

In order to create a weighting score for each criterion, a weighted matrix was created as shown in Table VI below. The criteria considered is the customer needs described in Section 2.0. Furthermore, each of the customer needs were compared directly with one another and a quantitative priority for each need was categorized. Based on the comparison between each individual customer need, a weighting was calculated as a percentage of the total customer needs. The weighted results of the customer needs comparison are shown below in Table V.

Table XVII: WEIGHTED MATRIX

Needs Number	Customer Requirements	Clean entire inside surface of the mixing bowl	Safe for operators	Eliminate operator climbing into the bowl	Safe transportation of hazardous wastes	Not generate heat to point of creating spark or explosion	Work for 420-gallon Baker-Perkins vertical mixer bowl	Keep the integrity of the mixing bowl	Easy and intuitive to operate	Retrofittable in the current processing plant	Long-life cycle	Decrease cleaning process time	Repeatable results	Work in warm environmental temperatures in the building	Under budget	Efficiently minimize operator involvement	Efficiently minimize the use of consumables
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Clean entire inside surface of the mixing bowl		2	3	1	5	1	1	1	1	1	1	1	1	1	1	1
2	Safe for operators			2	2	2	2	2	2	2	2	2	2	2	2	2	2
3	Eliminate operator climbing into the bowl				3	5	3	3	3	3	3	3	3	3	3	3	3
4	Safe transportation of hazardous wastes					5	6	4	4	4	4	4	12	4	4	4	4
5	Not generate heat to point of creating spark or explosion						5	5	5	5	5	5	5	5	5	5	5
6	Work for 420-gallon Baker-Perkins vertical mixer bowl							6	6	6	6	6	6	6	6	6	6
7	Keep the integrity of the mixing bowl								7	9	7	7	7	7	7	7	7
8	Easy and intuitive to operate									9	8	8	8	8	8	8	8
9	Retrofittable in the current processing plant										10	9	12	9	9	9	9
10	Long-life cycle											10	10	10	10	10	10
11	Decrease cleaning process time												12	11	11	11	11
12	Repeatable results													12	11	12	14
13	Work in warm environmental temperatures in the building														13	13	13
14	Under budget															15	14
15	Efficiently minimize operator involvement																15
16	Efficiently minimize the use of consumables																
	Total Hits	12	15	13	9	14	11	8	7	7	7	5	5	3	2	2	0
	Weightings	0.100	0.125	0.108	0.075	0.117	0.092	0.067	0.058	0.058	0.058	0.042	0.042	0.025	0.017	0.017	0.000

B.3.2 Concept Scoring

A quantitative analysis was done for the best 3 concept designs as identified from the concept screening in order to choose the single concept that will most likely will lead to a successful design based on the customer requirements. The rating was done on a scale of 1 to 5 where a one correlates to a design being significantly worse, a two correlates to a design being slightly worse, a three results in the design score being the same as the reference, a four means the design is slightly better and a five is excellent when compared to the relative performance of the selected design concept to current cleaning process. Furthermore, the design concepts will now be compared to the current cleaning process as the reference. This is because the concepts have already been screened through the ISRO process. Thus, in order to accurately determine a concept that is best suited for Magellan, the concepts will receive a score relative to the current cleaning process. The scoring works by multiplying the weight score, calculated by the weighted matrix, by the rating. The total summation of all the rankings will generate the best design concept for Magellan. The scoring process is shown in Table VI below.

Table XVIII: CONCEPT SCORING

		3.1		3.4		3.7.2		Current Process	
		Bowl Lubrication		Piston Cylinder Pressure		Combination of water and scraping			
Selection Criteria	Weight [%]	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Safe for operators	12.50	5	0.63	5	0.63	5	0.63	1	0.13
Not generate heat to point of creating spark or explosion	11.67	4	0.47	4	0.47	5	0.58	5	0.58
Eliminate operator climbing into the bowl	10.83	5	0.54	5	0.54	5	0.54	1	0.11
Clean entire inside surface of the mixing bowl	10.00	3	0.30	3	0.30	4	0.40	5	0.50
Work for 420-gallon Baker-Perkins vertical mixer bowl	9.17	5	0.46	5	0.46	5	0.46	5	0.46
Safe transportation of hazardous wastes	7.50	3	0.23	3	0.23	4	0.30	5	0.38
Keep the integrity of the mixing bowl	6.67	3	0.20	3	0.20	4	0.27	5	0.33
Retrofittable in the current processing plant	5.83	5	0.29	5	0.29	5	0.29	5	0.29
Easy and intuitive to operate	5.83	4	0.23	4	0.23	3	0.18	1	0.06
Long-life cycle	5.83	3	0.18	3	0.18	3	0.18	3	0.18
Repeatable results	4.17	3	0.13	3	0.13	4	0.17	4	0.17
Decrease cleaning process time	4.17	4	0.17	4	0.17	4	0.17	2	0.08
Work in warm environmental temperatures in the building	2.50	5	0.13	5	0.13	5	0.13	4	0.10
Under budget	1.67	3	0.05	3	0.05	4	0.07	5	0.08
Efficiently minimize operator involvement	1.67	3	0.05	3	0.05	4	0.07	1	0.02
Efficiently minimize the use of consumables	0.00	5	0.00	5	0.00	1	0.00	4	0.00
Total Score	100.00		4.03		4.03		4.41		3.46
Rank		3		2		1		4	
Continue?		Yes		No		Develop		No	

After adding all the weighted score for each criterion, the design concept 3.7.2, that is, a combination of water and scraping with extendable rods, ranked the highest. The total score was 4.41. Design concept 3.1 will also be considered for final design because it can be combined with design concept 3.7.2.

Furthermore, in order to get client feedback, a presentation was created to determine which concept design the client preferred. The clients preferred design solution aligned with the results from the scoring table and thus the concept that will continue into phase III of the project will be a combination of a design concept 3.1 and design concept 3.7.2.

B.4 Material Selection Process and Cost Analysis

The cost of the design concepts was not directly computed because the customer need for budget only had a 1.67% weighting from the design scoring process. Furthermore, the cost analysis of the design concepts considered a general cost for materials. With the concepts considering materials that are readily available in market and widely used in the aerospace industry. The market costs for the materials considered is outlined below in TABLE XIX.

TABLE XIX: COST ITEM AND PRICE RANKING [23] [24] [25]

Cost Item	Marketing Price (C\$)/Per
	Unit
Silicon	22.00/lb
Teflon	13.03/lb
Rubber	2.23/lb
Nylon	2.23/lb
Aluminum 6061	2.09/lb
Stainless steel	1.58/lb
Alloy steel	0.47/lb

Furthermore, the cost analysis and material selection process will be considered in more detail in phase III of the project.

B.5 Final Concept Design Summary

To summarize the concept selection process the design that advances to the detailed design section of the project will include a coating applied to the inside surface of the mixing

bowl, and a mechanical machine powered by pneumatic or hydraulic systems, with extendable arms that will be combined with pressurized water to remove the propellant. The materials considered for the final design will be determined based on the specific desired application. For example, Teflon will be considered for the coating because of its high chemical resistance, its low coefficient of friction, its hydrophobicity (repels water) and its high temperature resistance [19]. The model of concept design 3.7.2 is shown below.

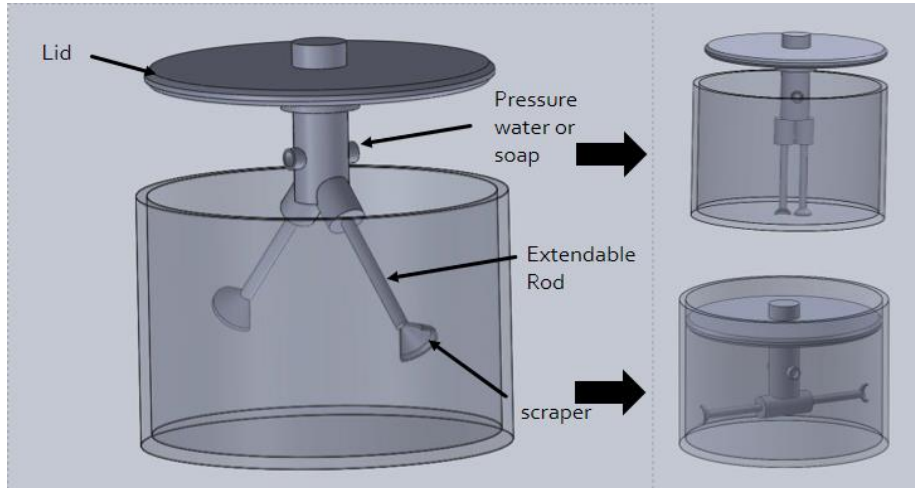


Figure 35: Design Concept 3.7.2

Appendix C: Pressurized Water System

This section will cover the pressurized water system that will help to remove some of the residual propellant. The pressurized water system is designed to spray both the side wall surfaces of the mixing bowl and the bottom surface. Furthermore, the water system has an external connection point and rotates concentric with the shaft.

C.1 Material Selection

Several Materials were considered for the selection of the pressurized water system. The metrics used to determine the materials include the following: corrosion resistance, the thermal capability, so that the design can work in the 120°F temperatures, the stiffness of the material so that the spinning motion will not cause the piping to deflect, the conductivity, to minimize the risk of an electrical current to ignite a spark, the strength to weight ratio of the material, and lastly the cost of the material.

Table XX: PIPE MATERIAL SELECTION

Material		PVC	Stainless Steel	Galvanized Steel	Copper	
Metrics	Corrosion Resistance	0.15	9	9	7	9
	Thermal Capabilities	0.1	3	9	10	9
	Stiffness	0.2	7	8	9	7
	Non-Conductive	0.4	10	9	9	1
	Strength-Weight Ratio	0.1	8	7	6	8
	Cost	0.1	8	6	6	4
Total Weight			8.65	8.75	8.65	5.25
Ranking			2	1	2	4

C.2 Pipe System Routing

For the pressurized water to contact all inside surfaces of the mixing bowl the water will have to be rotated around the bowl. Therefore, the water piping will have to be routed such that the system is able to rotate. This includes a swivel joint on the external connection point so that there will be no snagging or twisting of the external pressurized water tubes. The connection point will be located at the ball valve exit hole (at the bottom of the bowl) because the motor is located at the top of the shaft. The pipes will be routed such that the horizontal branches will exit through the holes of the shaft located above the arms of the blades. The piping will then be connected to the arms using p-clips to securely fasten the pipes during the rotational motion. The change in vertical to horizontal direction of flow will be used in Tee-joints (at the very top) and cross joints for the intermediate blade arms. The full routing is shown below in figure

C.3 Spray Nozzles Calculations

The pressurized water system will use many nozzles to cover the inside surface of the entire bowl. In order to accommodate the large size of the bowl and minimize the branch paths of the system the water will be optimized to have as few nozzles, or exits, as possible. Therefore, calculations were done to ensure that the nozzles cover the entire surface area.

The position of the branches is limited to 3 separate branches all located above the attachment point of the blade arms. Therefore, the design component that needed to be optimized was the spray angle of the nozzle, the distance from the surface of the bowl, and the contact angle on the surface of the bowl. Furthermore, considering the height of the blades to be 15 inches (381 mm), the spray height was set at 16 inches (406.4 mm). The calculations were performed as below.

The geometry for the hand calculations was approximated by the figures below

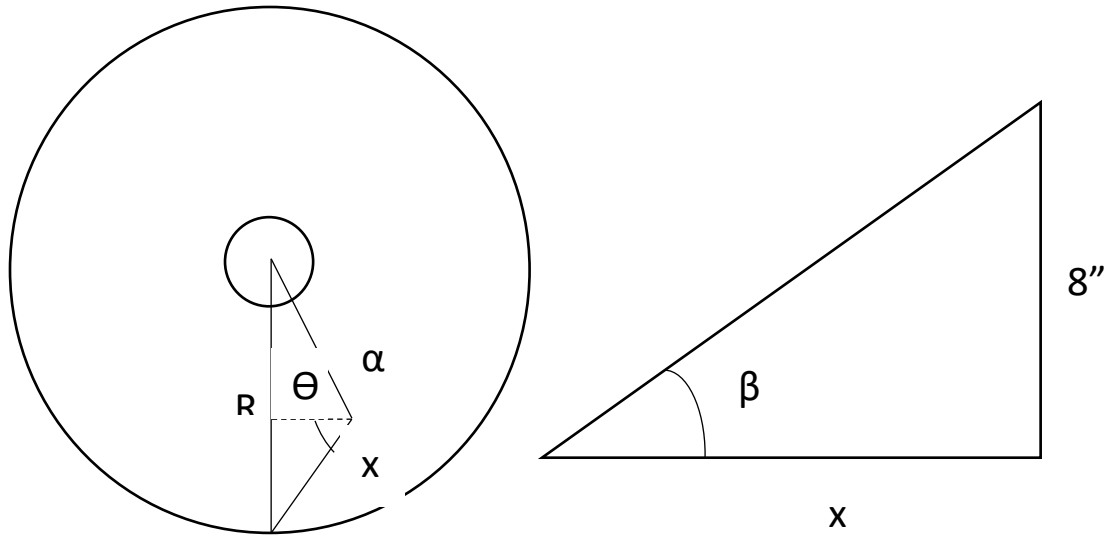


Figure 36: Geometry of Hand Calculation

Therefore, setting Beta to the stock sizes for nozzle spray widths, x was determined through equation,

$$x = \frac{\beta}{\tan(32.5)}$$

Furthermore, after determining the distance from the edge of the surface of the bowl, the contact angle was used to determine the distance from the center of the shaft. Considering the radius of the bowl to be 32 inches and $\theta = 45^\circ$. Alpha was determined through the cosine law to be,

$$= 24.77 \text{ inches}$$

Therefore, to adjust these values to stock size, the distance the nozzle should be placed from the center of the shaft will be 24 inches.

C.4 Flow Analysis

In order to ensure that the pressurized water will flow throughout the water system the model was simulated using computational fluid dynamics simulation software. The CFD was used to optimize the piping system so that each branch of the system would experience the correct amount of pressure forces to have the 14 different nozzles with the same amount of pressure

coming out. The results suggested a step-down nozzle to be introduced at the first cross connection point so that enough flow would be diverted in the horizontal direction. After the simulation was optimized the results can be seen below.

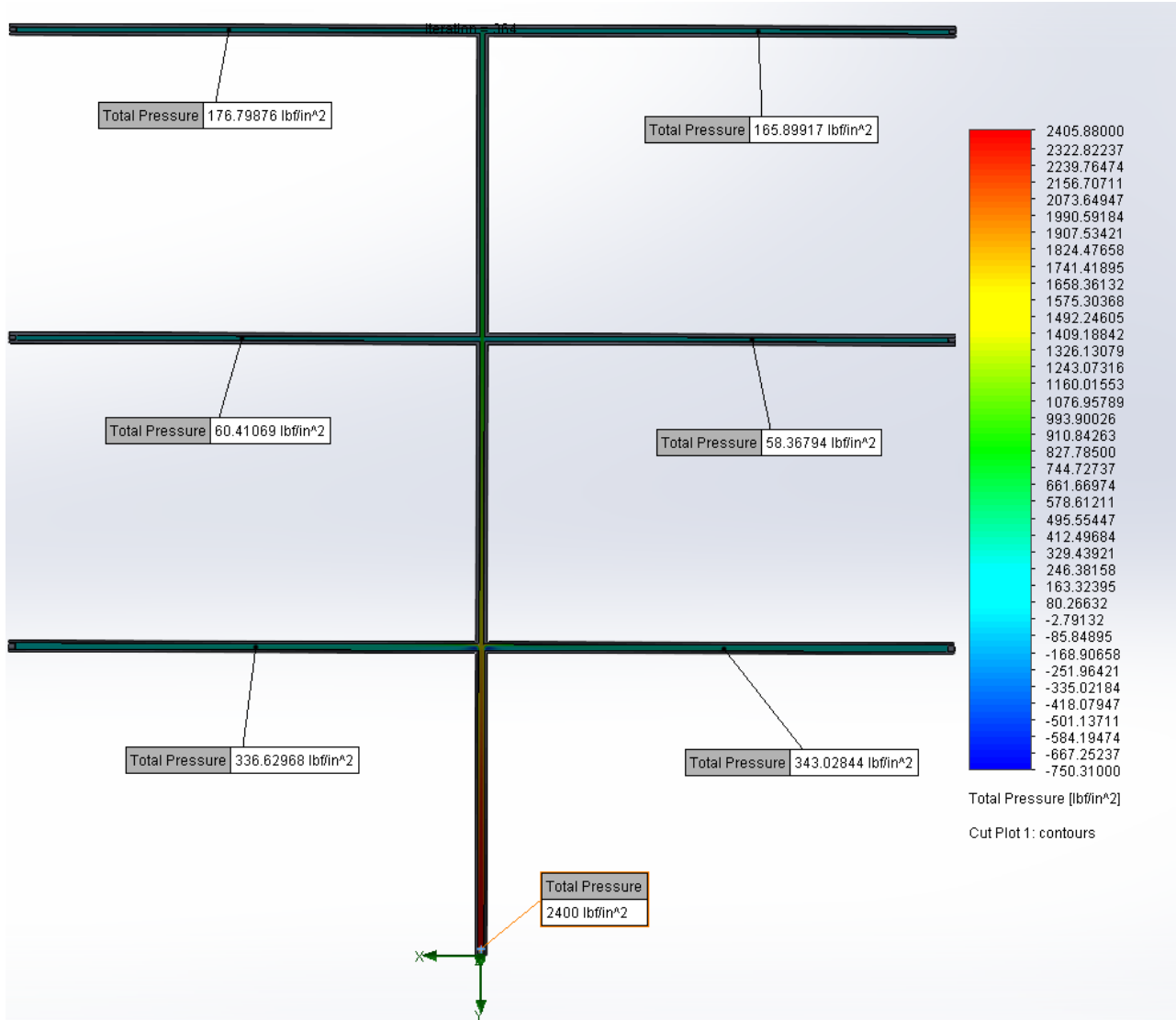


Figure 37: CFD Results for Flow Pressure

The higher pressures in the lowest branch is enough because this path of the flow will require more exit nozzles and thus have more pressure dissipation.

Appendix D: Shaft Design Details

Shaft is one of the main components in our design as it transmits power from the motor and helps align the blades onto the shaft to scrape the propellant from the side and bottom of the shaft. This section talks about the shaft optimization based on analytical results and Finite element analysis providing the safety of factor above 2.

D.1 Force Evaluation

In order to determine the shaft diameter that has a safety of factor above 3. Team assumed the shaft diameter to be 3 inches to get the required shape of the side scraper and the bottom scraper. Furthermore, a decision was made to have a hollow shaft to install the pressurized water system on the shaft. The next step was to evaluate the forces on the shaft in XY plane that is to the weight of the scraper blades and XZ plane due to force required to scrape the propellant from the walls.

To determine the forces on the shaft in YZ plane team was provided with an approximate force required to scrape the propellant by the operator that is 40 lbf and the information on width of the tool used to scrape the propellant was provided as 5 inches. From these parameters a distributed force of 40 lb / 5 inch was identified which is equivalent to 8 lb/inch.

Furthermore, client provided the information that the sides of the propellant mixing bowl requires less force compare to the bottom. However, to ensure the design can withhold the required force team used the same value for the side scraper.

In addition, a Teflon coating will be applied prior to mixing the propellant onto the mixing bowl this will reduce the force of 8lb/inch by significant amount. The static force of friction (μ) for steel on Teflon was identified to be 0.04 and the static force of friction (μ) for steel on rubber was identified to be 0.64. Therefore the reduced force of friction is identified by using the formula below:

$$\text{Reduced Friction} = \frac{\text{Coefficient of Static Force of Friction for teflon on steel}}{\text{Static Force of Friction for rubber on steel}}$$

From the equation above the reduced friction was identified to be 0.0625

Hence the required force for sides and bottom propellant force was calculated by multiplying the reduced friction force and uniform distributed force that is 8 lb/inch X 0.0625 = 0.5 lb/inch

Therefore after applying the Teflon coating the forces will be reduced by a factor of 16. These forces were then used to further identify the required torque. The goal for the force evaluation is to get an approximate value for the outside diameter of the shaft to ensure the safety factor is above 2 for static and fatigue analysis and compare the initial assumption of the shaft diameter to the calculated results. In order to simplify the calculations number of assumptions were made such as:

1. The blades were aligned at 60° from each other however to simplify the calculation it was assumed that all the blades are aligned at the same plane.
2. The holes on the shaft for water line and the hub key seat for transmitting the power was not considered for the analytical result.
3. The profile of the bottom scraper was considered as a cantilever beam to simplify the calculation.

Furthermore, the Finite Element Analysis (FEA) was performed to get confidence on the analytical results and to ensure the safety factor is above 2 and account for the assumptions as mentioned above.

D.1.1 Force Evaluation in XY plane

This section reflects on how the forces were evaluated for XY plane. Figure 38 represents the Free Body Diagram for the forces in XY direction which are mainly due to the weight of the side and bottom scrapers.

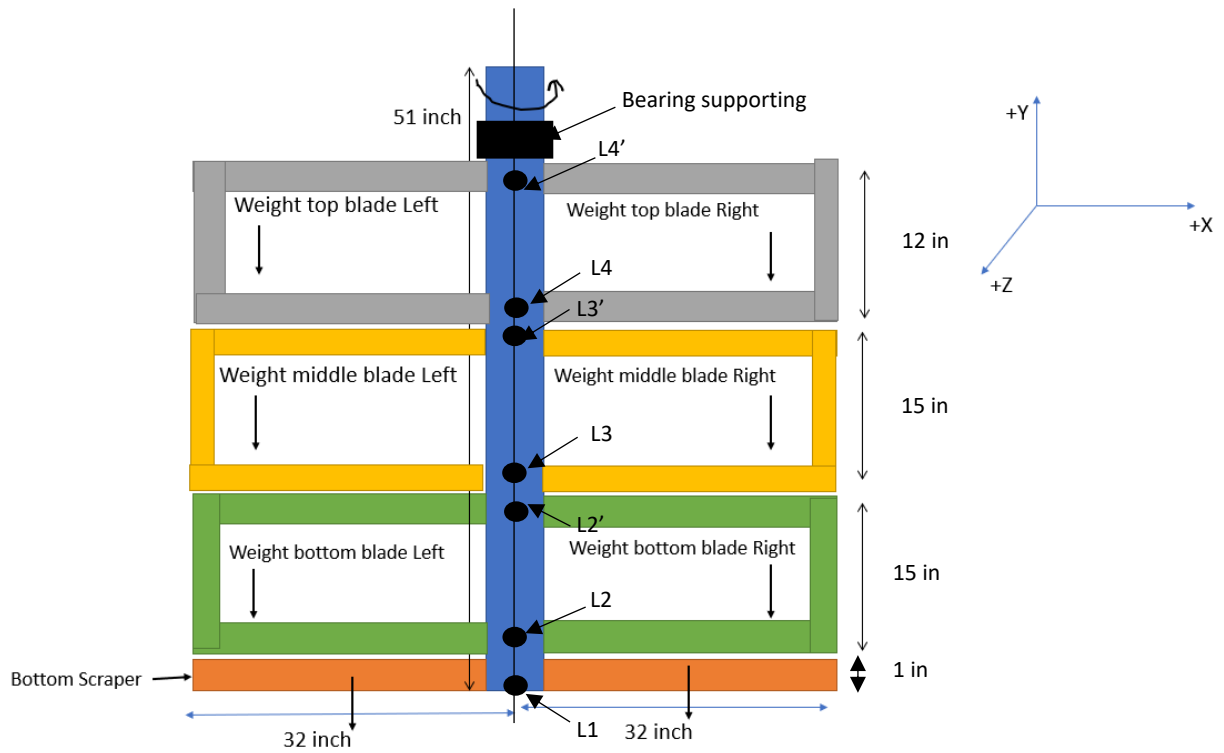


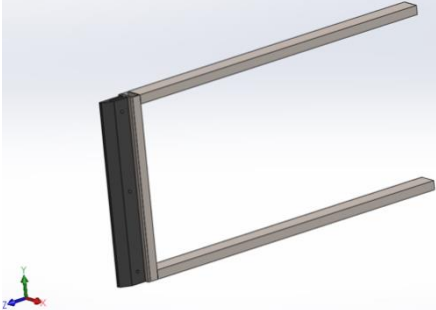
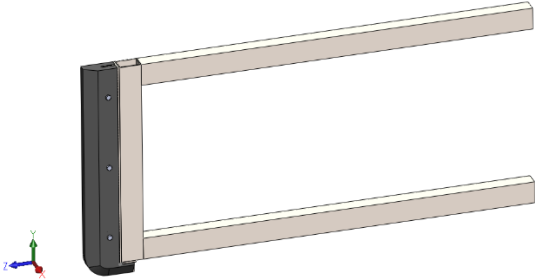
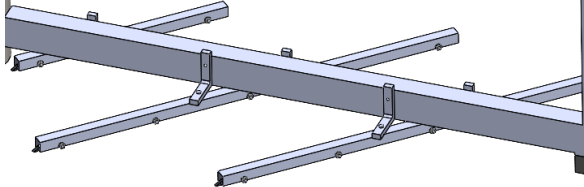
Figure 38: Free Body Diagram in XY direction

In order to get the geometry of the blades the shaft diameter was assumed to be 3 inches to get the weight of the sub-assembly including rubber on the sides (neoprene) and the frame that is (Stainless steel 316) as identified below.

TABLE XXI: WEIGHT [LB] AND COG OF THE SUB-ASSEMBLY OF SIDE SCRAPERS AND BOTTOM SCRAPER

Blade	Geometry	Weight
Top blade		<p>Mass properties of top blade Configuration: Default Coordinate system: -- default --</p> <p>Mass = 7.97 pounds Volume = 39.68 cubic inches</p> <p>Centre of Gravity: 26in</p>

TABLE XX: WEIGHT AND COG OF THE SUB-ASSEMBLY OF SIDE SCRAPERS AND BOTTOM SCRAPER
(Continued)

Blade	Geometry	Weight
Middle blade		<p>Mass properties of middle blade Configuration: Default Coordinate system: -- default --</p> <p>Mass = 8.76 pounds Volume = 45.08 cubic inches</p> <p>Centre of Gravity: 26in</p>
Bottom blade		<p>Mass properties of bottom blade Configuration: Default Coordinate system: -- default --</p> <p>Mass = 8.38 pounds Volume = 52.61 cubic inches</p> <p>Centre of Gravity: 26in</p>
Bottom Scraper		<p>Mass: 7.7 lbs Assumed centre of gravity: 16 in</p>

Based on the information provided in **Error! Reference source not found.** the forces and moment on the shaft in xy plane was calculated. The weight of the subassemblies for bottom and side scrapers are acting downwards which can be represented as negative value in y direction. Furthermore, the blades that are attached parallel to each other have similar cross section and weight. Therefore the net force acting on the shaft will be the addition of these weight in the positive y direction. In addition, the positive moment refers to moment in clockwise direction and negative moment refers to the moment in counterclockwise direction which gives the resultant moment on the shaft axis to be 0 as identified in TABLE XXII below. The location L1,

L2, L2', L3, L3', L4 and L4' as shown in Figure 38 are the location on the central axis of the shaft where the forces will be evaluated.

TABLE XXII: FORCE AND MOMENT CALCULATIONS FOR SHAFT IN XY PLANE

Description	Net Force on the shaft (xy plane) [lb]	Moment on the central axis of shaft due to left blade [lb.in]	Moment on the central axis of shaft due to right blade [lb.in]	Net moment on the shaft [lb.in]
L1	+15.40	-123.2	+123.2	0
L2	+8.38	-217.88	+217.88	0
L2'	+8.38	-217.88	+217.88	0
L3	+8.76	-227.26	+227.26	0
L3'	+8.76	-227.26	+227.26	0
L4	+7.97	-207.22	+207.22	0
L4'	+7.97	-207.22	+207.22	0

The resultant force at bearing location can be identifies as the sum of forces in y direction that is 65.62 lb. This force will create a moment along Z axis that is calculated as 65.62 lb X 6 in = 393. 72 lb.in

D.1.2 Force Evaluation in XZ plane

The free body diagram for the XZ plane is shown in Figure 39 below. As the transmission shaft rotates in counter-clockwise direction the force F1 and F1' are the force required to scrape the propellant from the sides of the propellant mixing bowl which will be equal and opposite in direction for all 3 different blades. Furthermore, F2 and F2' are the force required to scrape the propellant from the bottom of the scraper.

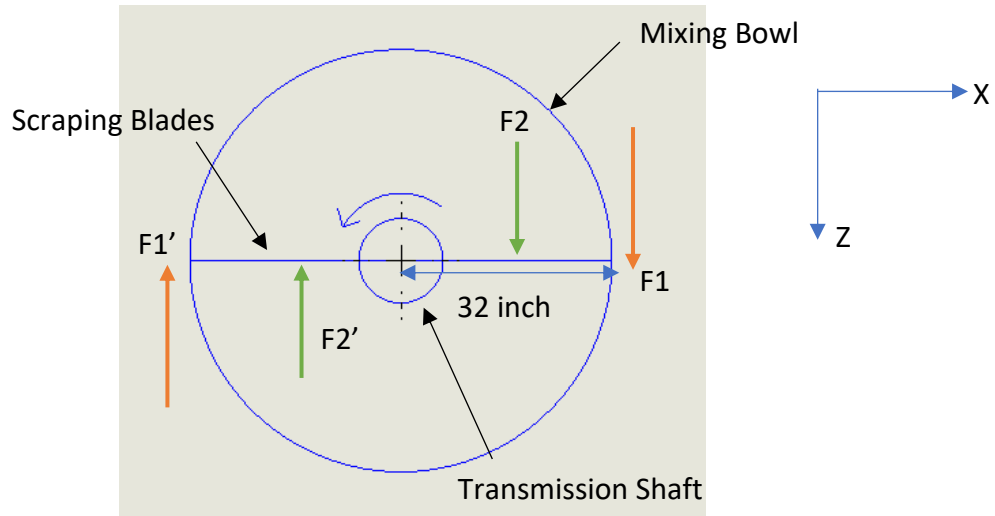


Figure 39: Force in XZ direction acting on the side scrapers

Figure 40 represents the shear and bending moment diagram generated using an online software [26] providing the distributed load on a cantilever beam for the bottom scraper blade as 0.5 lb/in and 32 inch from the axis of rotation of the shaft to the end of the scraper blade.

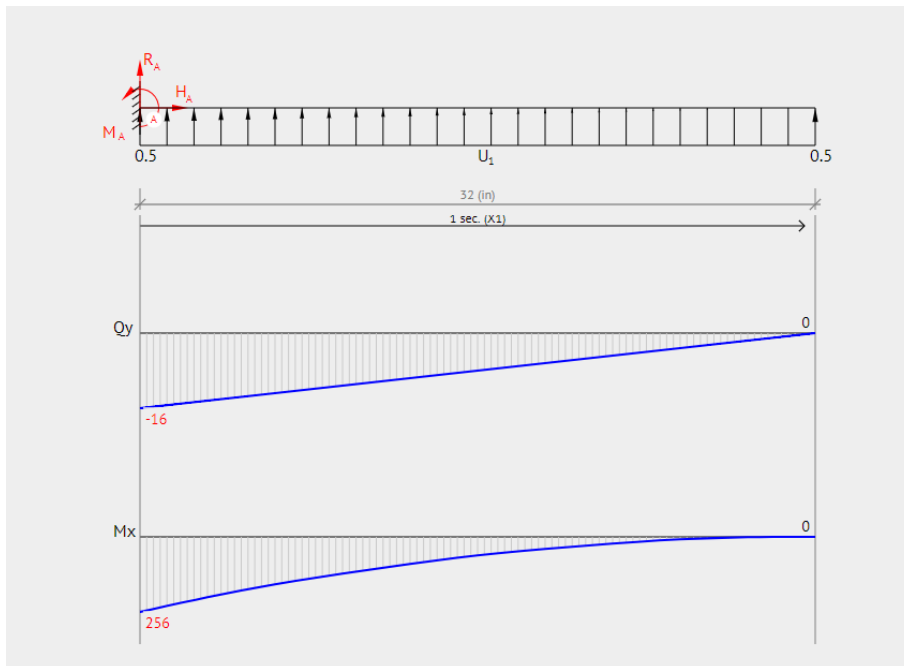


Figure 40: Shear and Bending moment Diagram for Bottom scraper (XZ Direction) [26]

In order to evaluate the force on the side scraper for bottom, middle and top the distributed load of 0.5 lb/in was evaluated by considering it as a beam with two fixed support and was evaluated as shown in Figure 41 below.

$$\begin{aligned}
 R = V & \dots\dots\dots = \frac{w\ell}{2} \\
 V_x & \dots\dots\dots = w\left(\frac{\ell}{2} - x\right) \\
 M_{\max} \text{ (at center)} & \dots\dots\dots = \frac{w\ell^2}{8} \\
 M_x & \dots\dots\dots = \frac{wx}{2}(\ell - x) \\
 \Delta_{\max} \text{ (at center)} & \dots\dots\dots = \frac{5w\ell^4}{384 EI} \\
 \Delta_x & \dots\dots\dots = \frac{wx}{24 EI}(\ell^3 - 2\ell x^2 + x^3)
 \end{aligned}$$

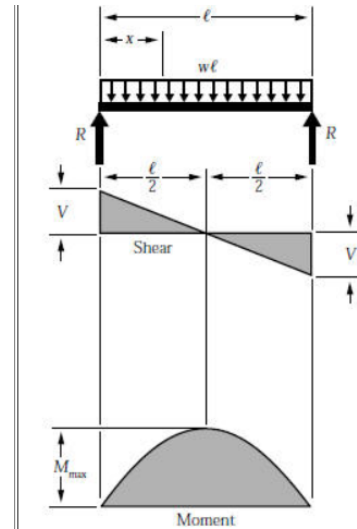


Figure 41: Calculations for the side scraper by considering it as a beam with 2 fix ends [27]

In order to evaluate the force on the side scraper the above equation shown in Figure 41 was used to evaluate the shear force to further calculate the moment on the different location on the shaft for the side scraper. Moreover, the distributed load for the side scraper was assumed to be same as for the bottom scraper that is 0.5 lb/in and the length of the scrapers for bottom, middle and top side scrapers are shown in Figure 38. The results for the forces and moment along XZ plane are shown in TABLE XXIII below.

TABLE XXIII: FORCE AND MOMENT CALCULATIONS FOR SHAFT IN XZ PLANE

Description	Force on the central axis of shaft due to left blade [lb]	Force on the central axis of shaft due to right blade [lb]	Net Force on the shaft (XZ plane) [lb]	Moment on the central axis of shaft due to left blade [lb.in]	Moment on the central axis of shaft due to right blade [lb.in]	Net moment on the shaft [lb.in]
L1	-16	+16	0	+256	+256	+512
L2	-3.75	+3.75	0	+120	+120	+240
L2'	-3.75	+3.75	0	+120	+120	+240
L3	-3.75	+3.75	0	+120	+120	+240
L3'	-3.75	+3.75	0	+120	+120	+240
L4	-3	+3	0	+96	+96	+192
L4'	-3	+3	0	+96	+96	+192

It is to be noted that the max moment will have to be calculated in the YZ plane however, as the moments on the left side and right side will be equal and opposite in direction they will cancel out and net moment on the shaft will be zero therefore the forces in the YZ plane were not evaluated. Figure 42 represents the net forces and moments that are acting on the shaft.

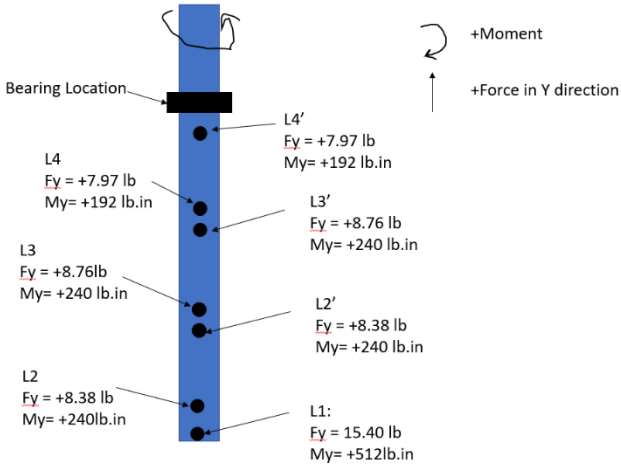


Figure 42: Net Forces on a shaft

The torque can be calculated as the resultant:

$$\sqrt{(\text{moment sum of moment on Z axis})^2 + (\text{moment sum of moment on Y axis})^2}$$

Therefore the torque was identified to be $\sqrt{(1856)^2 + (393.72)^2} = 1897 \text{ lb.in}$ this value can be approximated to 1900 lb.in. A service factor of 1.25 was used for motors with low power and low speed [28] therefore the torque of the shaft was calculated as **2565 lb.in.**

The next step was to calculate the shaft diameter based on the calculations from force analysis. To provide an ease of manufacturing and avoid any complexity team considered the minimum shaft diameter for the location of the shaft where it experiences the maximum stress that will be the top of the shaft

D.2 Minimum Shaft Diameter Calculations

The material used to construct the transmission shaft was determined to be Stainless steel -316 due to its high strength, good machinability and its ability to be non-static as mentioned above in appendix C. The safety factor was considered to be 3 for the shaft design as there were

number of assumptions that were made hence this indicates there is a moderate level of uncertainty [29].

From a yielding standpoint, the shear strength of Stainless steel -316 Steel is required to determine the minimum shaft radius that can be implemented in the crankshaft design. This was found from Solid work simulation as $\tau_{yld} = 290$ MPa. Therefor with safety factor of 3 $\tau_{allowable} = 96.67$ MPa that is 14020 lb/in². The required diameter of the shaft based on static analysis was calculated as

$$\tau_{max} = \tau_{yld} = \frac{Tc}{J} \rightarrow 14020 \text{ lb/in}^2 = \frac{(2565 \text{ lb. in})Ro}{\frac{\pi}{2}(Ro^4 - Ri^4)}$$

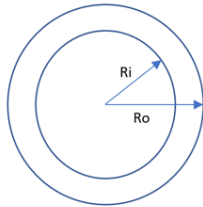


Figure 43: Cross-section Area of Main Shaft

We know the $R_i = 1$ inch and from the equation above the R_o was identified to be 1.029 in therefor diameter is 2.06 inch

The section below describes the minimum shaft diameter obtained from fatigue analysis. The diameter of the transmission shaft is calculated using the DE-Soderberg equation found from Shigley's Machine Design [30]. This will allow us to get a minimum shaft diameter based on the fatigue analysis.

$$d = \left(\frac{16n}{\pi} \left\{ \frac{1}{S_e} [4(K_f M_a)^2 + 3(K_{fs} T_a)^2]^{\frac{1}{2}} + \frac{1}{S_{yt}} [4(K_f M_m)^2 + 3(K_{fs} T_m)^2]^{\frac{1}{2}} \right\} \right)^{1/3} \quad \text{Equation 1}$$

Here, M_m and M_a represent the midrange and alternating bending moments, T_m and T_a represent the midrange and alternating torques, and K_f and K_{fs} represent the fatigue stress-concentration factors for bending and torsion, respectively.

For a rotating shaft with constant bending and torsion, bending stress is completely reversed and torsion is steady. In this transmission shaft analysis, M_m and T_a are constants, and so Equation 1 simplified by setting M_m and T_a to 0.

$$D = \left[\frac{32 * N}{\pi} \sqrt{\left(\frac{k_t M}{S_n} \right)^2 + \frac{3}{4} \left(\frac{T}{S_y} \right)^2} \right]^{\frac{1}{3}} \quad \text{Equation 2}$$

Here S_n and S_y are the actual endurance strength and yield strength of the material, N and k_t are the design factor and stress concentration factor.

The minimum diameter of the shaft is obtained by determining the actual endurance strength of the material and then subsequently choosing the value of the design factor. Team used $N= 3$ for the shaft design, which indicates a moderate level of uncertainty about actual material strengths, loading conditions and long-term environmental factors. The yield strength for stainless steel 316 is 290 [MPa] as identified in the solid works simulation.

The operating condition for the machine part is different from those for which the basic endurance strength was determined [12]. The ultimate strength of the stainless steel 316 is found to be 300 [MPa]. The equation for the pristine endurance limit is found in Shigley [30], which provides an Equation 3 as shown below.

$$\sigma_e = k_a k_b k_c k_d k_e k_f \sigma'_e$$

Equation 3

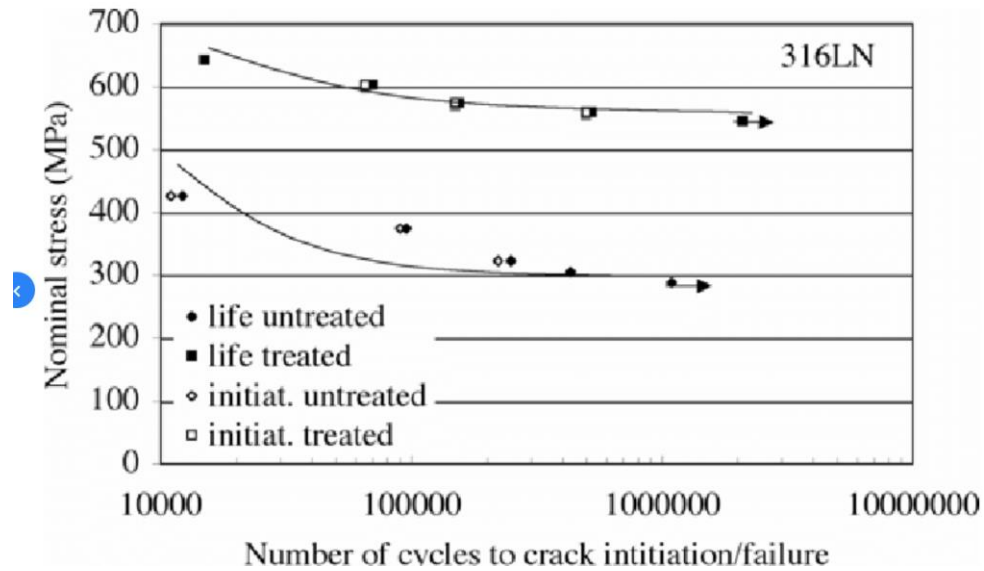


Figure 44: SN Curve for Stainless Steel 316

Figure 44 gives relationship between the pristine endurance strength (σ'_e) and number of cycles to failure. These results are obtained from laboratory experiment under ideal condition.

Total life of output shaft is 4000 hours to convert number of hours for failure to number of

cycles we can use the relation $RPM \left(\frac{rev}{min} \right) \times life (number\ of\ hours) \times \frac{60\ min}{1\ hour}$ with the

output speed of 7rpm. The number of cycles to failure N_f is determined to be (1.6E +06 cycles).

From the figure above the pristine endurance strength (σ'_e) was identified to be **300 MPa**. It

was also identified that the shaft will be designed for an infinite life as the number of failures passes the endurance limit.

The number of variable factors used for calculating the actual endurance limit are shown in

TABLE XXIV below:

TABLE XXIV: DIFFERENT FACTORS EFFECTING THE ENDURANCE STRENGTH

Ka(Surface condition modification factor)(Ground)	0.266039873
Kb (Size Factor)	0.79470492
Kc(load modification factor)	1
Kd(Temp Modification factor)	1.01
Ke(Reliability Factor)	0.753
Kf (Miscellaneous effect factor)	1
Real endurance Strength	6996.4 Psi

Substituting the value for $S_n = 6996.4$ Psi, $M = 393.72$ MPa, $T = 1856$ Lb.in, $S_y = 42060.9$ Psi and $K_t = 1.6$ as the hub will have a profile of a sled runner.

Therefore, the minimum diameter was calculated as 1.45 inch as this formula gives the diameter for the shaft assuming it's a solid shaft therefor on order to get a outside diameter of the hollow shaft the outside diameter was calculated as $(D^3 + D_{inside}^3)^{1/3}$ which was identified to be 2.23 inches. Therefore, our assumption earlier made for shaft diameter of 3 inch will be sufficient to provide a safe design.

Once the required torque was ide

In addition, the FEA analysis was performed to ensure the shaft diameter of 3 inch provides a safety factor of 3 or above. As shown in calculations above the shaft diameter based on the fatigue analysis was 2.23 inches however it was assumed at the beginning that the shaft diameter of 3 inch will be enough to provide the torque and support the load of the side plates.

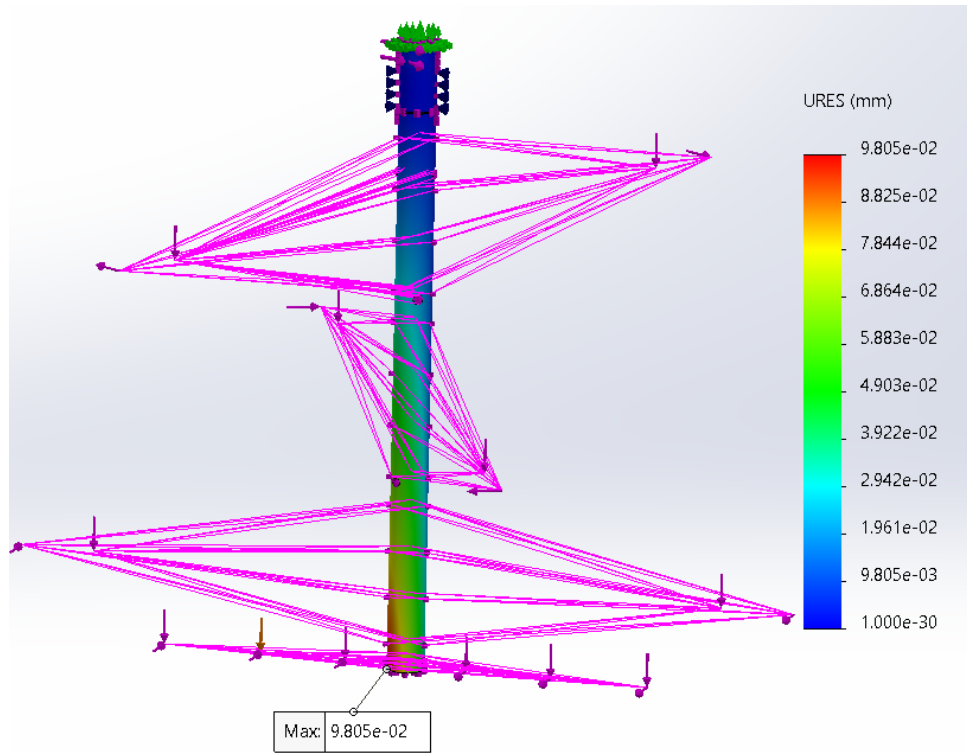


Figure 45: Maximum deflection on the transmission shaft

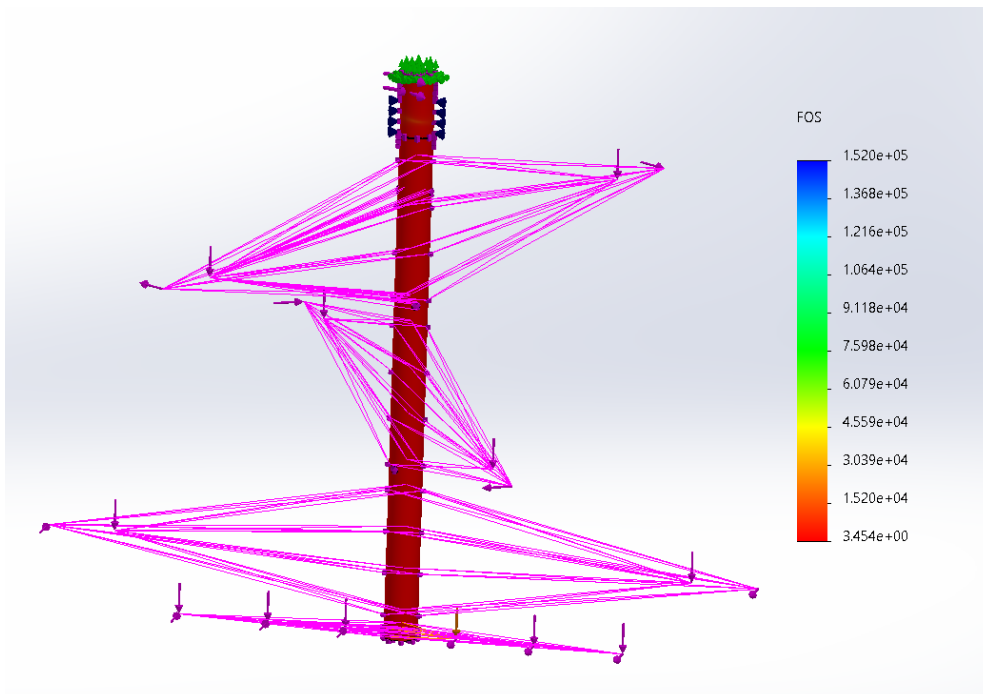


Figure 46: Factor of Safety of Transmission Shaft

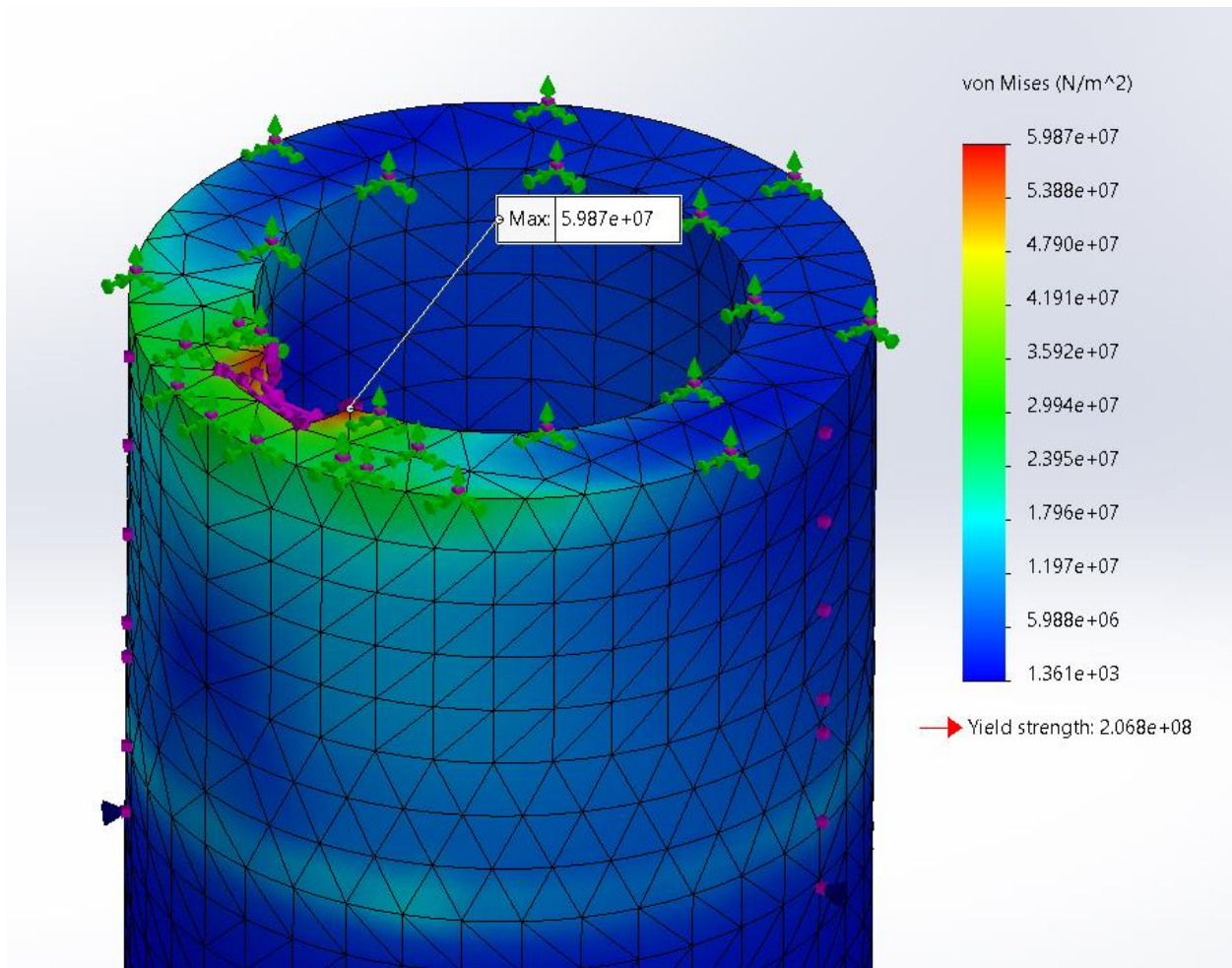


Figure 47: Maximum Von-Mises Stress on a transmission shaft

As shown Figure 45. Figure 46 and Figure 47 the maximum deflection of the shaft is 0.004 inch and provides a safety factor of above 3 with maximum stress on the hub key of 5.98×10^7 N/m². Therefore, overall, we can say that the shaft diameter of 3 inch will be successfully able to provide a required torque of 2565 lb and it will be able to support the designed load.

Appendix E: Bearing calculations

The bearing calculation was performed to ensure if the selected mounted roller bearing will be enough for the design requirement. The recommended design life for bearing is considered to 30,000 hours considering the cleaning equipment is a general industrial machine [12]. The number of design revolutions for the bearing can be calculated as $L_d = h (rpm) (60 \frac{min}{h})$ [12].

Here h is the specified design life in hours = 30,000 hours.

Rpm = 7;

Therefore, $L_d = 1.26 \times 10^7$ rev

The roller bearing carries the dynamic loading of the net weight of side and bottom scraper and it was identified to be $P_d = 65.62$ lb as identified in section D.1.1 Force Evaluation in XY plane. Therefore, basic dynamic load rating can be calculated as $C = P_d(L_d/10^6)^{1/k}$, where $k = 3.33$ for roller bearing. Substituting the values for P_d , L_d and k the dynamic load rating is calculated as 140.44 lb.

The Dynamic thrust load capacity of the selected mounted roller bearing is 5150 lbs [13] which is way above the calculated dynamic load rating. Therefore, the selected bearing will work sufficiently well for our design. However, it is suggested to lubricate the bearing before each operation with grease with lithium thickener as suggested by supplier [13] to ensure long life of bearing.

Appendix F: Key selection for shaft and hub

This section talks the process and calculation that helped team to determine the size and length of the key used for coupling the transmission shaft with coupler.

The size of the key was determined to be square with width of 0.5 in and Height of 0.5 inch as shown in table 11.1 [12]. The suitable design factor N was identified to be 3 which is adequate to accommodate for accidental overloads and shock. The material of the key was identified to be 416 Stainless steel which has lower strength compare to stainless steel 316 used for shaft and a coupler. The yield strength of the 416 stainless steel is 39,900 psi.

In order to identify the minimum length required for the key the following equation will be used because the key is square, and the key material has the weakest strength.

$L_{min} = \frac{4TN}{DWS_y}$; Here T is the torque that is 2565 lb.in as calculated in section D.1.2 Force

Evaluation in XZ plane, N is 3, D = 2 inch inside diameter of the shaft, W = 0.5 inch and $S_y = 39,900$ psi. Substituting these values for equation L_{min} the minimum length of the key was calculated as 0.77 inches. Therefor we can specify the length of the key to be 1 inch.

In summary, the key has the following characteristics:

Material: Stainless Steel 316

Width: 0.500 in

Height: 0.500 in

Length: 1 inch

Appendix G: Side Blades Detailed Design

G.1 Blade Material Selection

The metallic material selection is focused on comparing the properties of stainless steel 304, stainless steel 316 and aluminum 6061 T6 because they are all non-sparkle material and they are easy to weld with each other. Based on the design of each component, the properties have been selected as following: density, yield strength, hardness, corrosion resistance and cost. All these properties have been selected to finalize the component that the material should be applied to.

TABLE XXV: METAL MATERIAL PROPERTY [14] [31] [32] [33]

Material	Density (lb/in ³)	Yield Strength (MPa)	Hardness (Rockwell B)	Corrosion Resistance ranking	Cost (\$/lb)
Stainless Steel 304	0.289	215	70	2	0.56
Stainless Steel 316	0.289	290	79	1	0.78
Aluminum 6061 T6	0.0975	276	60	3	0.45

The weight decision matrix is shown below to demonstrate the scoring of these properties. As it shown, the most important property that has been considered is yield strength and the cost is the last criterion listed.

TABLE XXVI: WEIGHT DECISION MATRIX FOR METAL MATERIAL

Property	Density	Yield Strength	Hardness	Corrosion Resistance	Cost	Scoring	Weighting
Density	-	0	0	0	1	1	0.1
Yield Strength	1	-	1	1	1	4	0.4
Hardness	1	0	-	0	1	2	0.2
Corrosion Resistance	1	0	1	-	1	3	0.3
Cost	0	0	0	0	-	0	0.0

Based on the weight decision matrix and material properties, the final weight of each material can be calculated to determine the results.

TABLE XXVII: METAL MATERIAL SELECTION

Material		Stainless Steel 304	Stainless Steel 316	Aluminum
	Density	0.1	1	3
Metrics	Yield Strength	0.4	1	2
	Hardness	0.2	2	3
	Corrosion Resistance	0.3	2	1
	Cost	0.0	2	3
Total Weight			1.5	2.2
Ranking			2	1

As a result, the aluminum 6061 T6 and stainless steel 316 have a better result comparing to Stainless Steel 304.

The material chosen for mounting plate and motor stand is aluminum 6061 T6 due to its low density.

The material chosen for shaft is stainless steel 316 due to its high yield strength.

The material chosen for hardware is stainless steel 316 due to its high corrosion resistance.

The material chosen for blade frame is stainless steel 304 because of the restriction of design geometry. Stainless steel 304 is the only material we consider and provide the material geometry we need.

G.2 Scaper Material Selection

Rubber material are applied to the side scrapers to scrape the inner surface. Therefore, a material selection of rubber material is shown below to determine the best material that can be applied to meet design constraints.

The following table is the rubber material that be taken into consideration including properties such as resilience, water resistance, abrasion resistance, maximum temperature and cost.

Based on the research on material property, they use following standard to identify the quality of the material.

Excellent – 5; Very Good – 4; Good – 3; Average – 2; Poor – 1.

TABLE XXVIII: RUBBER MATERIAL PROPERTY [34]

Rubber Material	Resilience (Rebound)	Water Resistance	Abrasion Resistance	Maximum Temperature (°F)	Cost Ranking
Neoprene	3	5	5	280	4
Polyurethane	4	1	5	175	1
Natural	5	4	5	180	6
EPDM	3	5	4	350	5
Fluoroelastomer	4	4	3	600	2
Silicone rubber	4	5	2	550	3

The weight decision matrix is shown below to indicate the priority of property. The properties were compared while considering the design condition. Therefore, the most important criteria is abrasion resistance because the scraper is scraping the surface during entire process, a high abrasion resistance need to be considered and the last one is the cost of material.

TABLE XXIX: WEIGHT DECISION MATRIX FOR RUBBER MATERIAL

Criteria	Resilience (Rebound)	Water Resistance	Abrasion Resistance	Maximum temperature	Cost	Score	Weighting
Resilience (Rebound)	-	1	0	1	1	3	0.20
Water Resistance	0	-	0	1	1	2	0.13
Abrasion Resistance	1	1	-	1	1	4	0.26
Maximum temperature	0	0	0	-	1	1	0.06
Cost	0	0	0	0	-	0	0.00

Based on the weight decision matrix and material properties, the final weight of each material can be calculated to determine the results.

TABLE XXX: RUBBER MATERIAL SLECTION RESULTS

Material		Neoprene	Polyurethane	Natural	EPDM	Fluoroelastomer	Silicone	
Metrics	Resilience (Rebound)	0.20	3	4	5	3	4	4
	Water resistance	0.13	5	1	4	5	4	5
	Abrasion Resistance	0.26	5	5	4	4	3	2
	Maximum Temperature	0.06	2	1	1	4	5	4
	Cost	0.00	4	1	6	5	2	3
Total Weight			2.67	2.29	2.62	2.53	2.4	2.21
Ranking			1	5	2	3	4	6

Therefore, the most suitable rubber is neoprene rubber material. Since rubber material has different hardness, the harder the rubber property, the less displacement it will have when scraping the propellant. Therefore, the hardness Shore 70A has been selected because the hardness of this material is similar to the shoe heel, as it is shown in the table below.

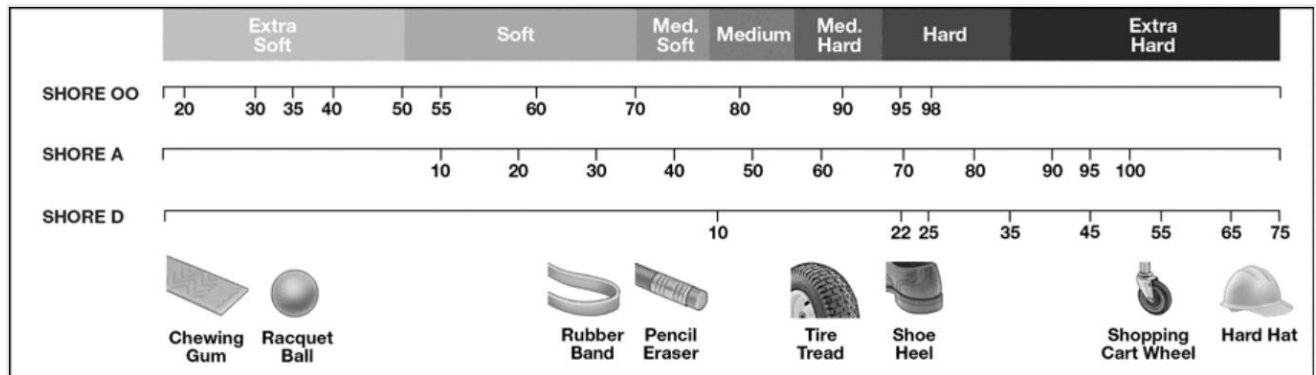


Figure 48: Rubber Hardness Reference Table [35]

Therefore, neoprene rubber with hardness A70 has been selected for the side scraper.

G.3 Side scraper detailed size and calculation

The side scrapers are designed with three hollow rectangular frame that are welded together as a horizontal U-shape, and a T-bar shape frame is also welded on the middle vertical frame worked as a key. A Neoprene Rubber with a slit is design to fit the T-bar frame perfectly. Then, screws, washers and nuts are used to fixe the rubber scraper to prevent falling off from the blade. A round cut at the corner of the rubber scraper is design to easily slide the blade inside of the mixer bowl.

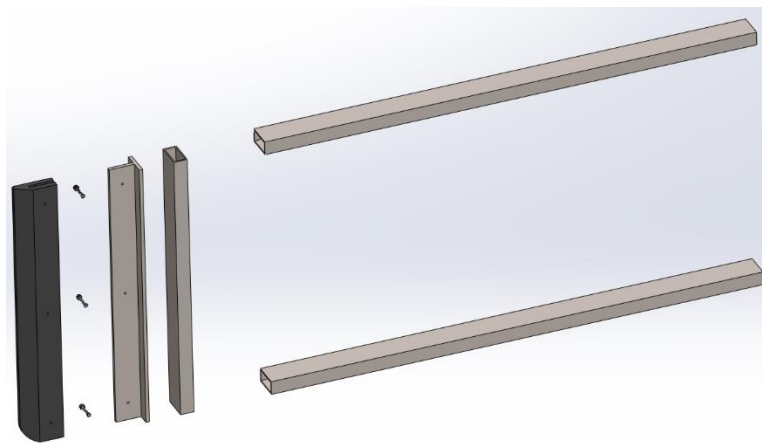
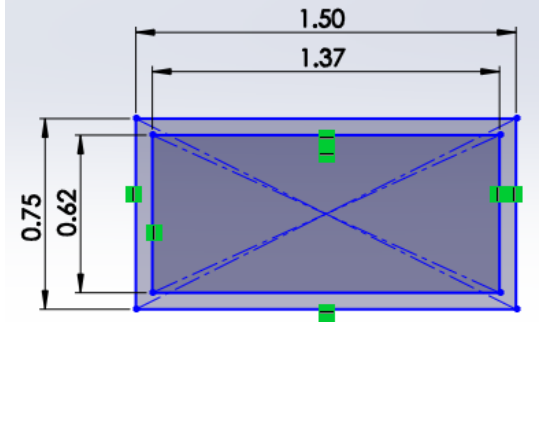
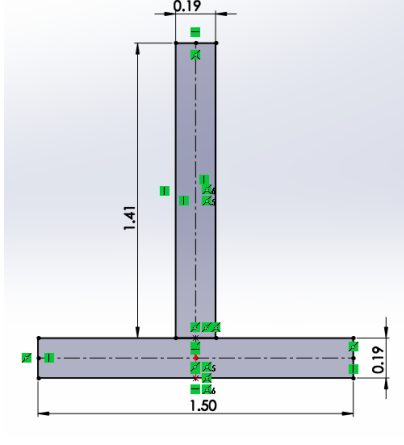
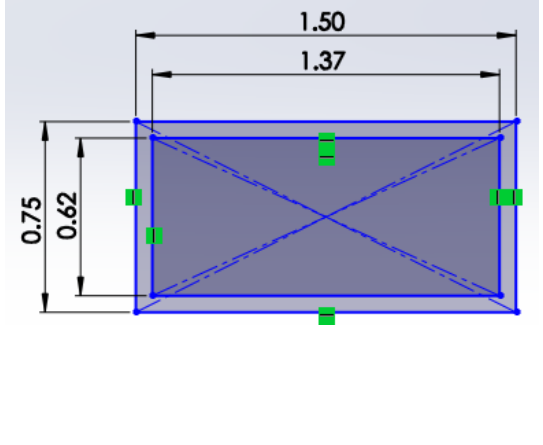
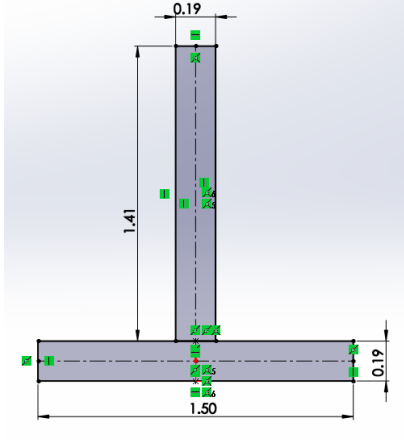
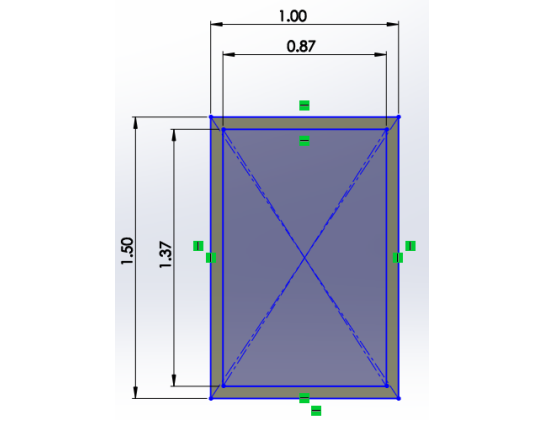
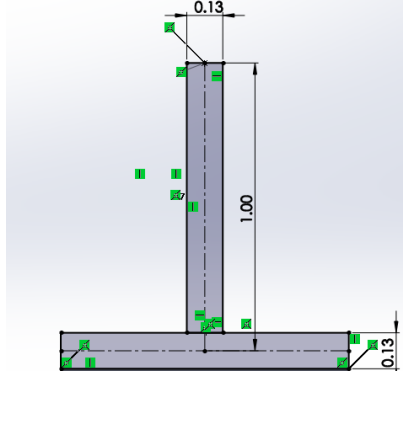


Figure 49: Exploded View of Side Blade

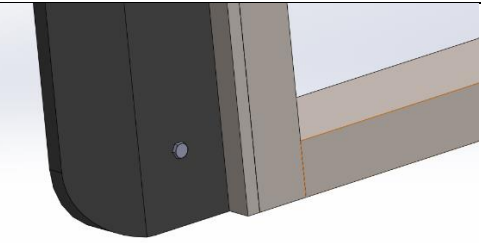
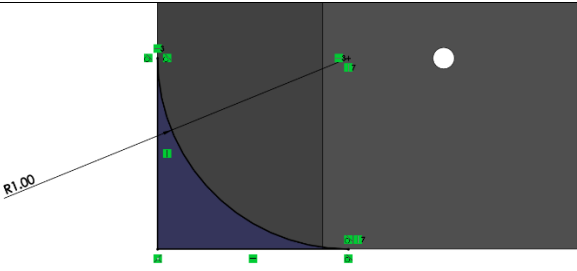
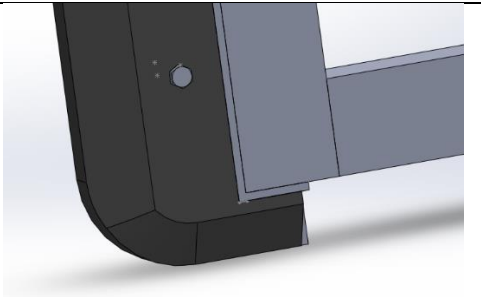
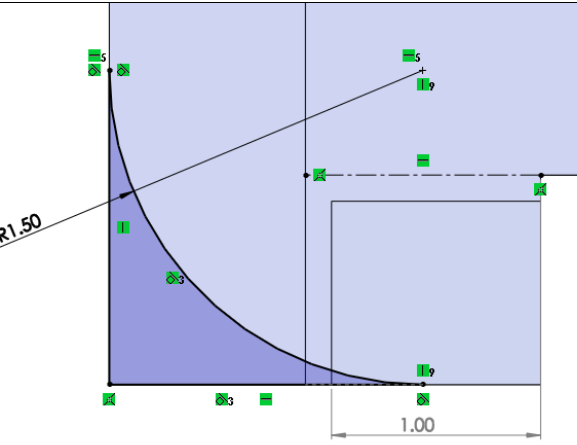
The following table shows the detailed cross-section area and length of each blade:

TABLE XXXI: DETAILED DESIGN GEOMETRY FOR EACH BLADE

Blades	Height (inch)	Rectangular Tube Cross-section (inch)	T Bar Cross-section (inch)
Top	12.3	 <p>Diagram showing a rectangular tube cross-section with dimensions: outer width 1.50, inner width 1.37, outer height 0.75, and inner height 0.62. The tube is shaded blue with dashed lines indicating internal structure.</p>	 <p>Diagram showing a T-bar cross-section with dimensions: stem width 0.19, stem height 1.41, and flange width 1.50. The flange thickness is 0.19. The stem is shaded gray.</p>
Middle	15	 <p>Diagram showing a rectangular tube cross-section with dimensions: outer width 1.50, inner width 1.37, outer height 0.75, and inner height 0.62. The tube is shaded blue with dashed lines indicating internal structure.</p>	 <p>Diagram showing a T-bar cross-section with dimensions: stem width 0.19, stem height 1.41, and flange width 1.50. The flange thickness is 0.19. The stem is shaded gray.</p>
Bottom	15	 <p>Diagram showing a rectangular tube cross-section with dimensions: outer width 1.50, inner width 1.37, outer height 1.00, and inner height 0.87. The tube is shaded blue with dashed lines indicating internal structure.</p>	 <p>Diagram showing a T-bar cross-section with dimensions: stem width 0.13, stem height 1.00, and flange width 1.50. The flange thickness is 0.13. The stem is shaded gray.</p>

To properly fit the side scraper inside the mixer bowl, a 1-inch radius cut is designed for top and middle blade. It helped the operator to easily slide the blade into the mixer bowl with a In order to install the bottom scraper on the bottom blade, the cross-section area of the bottom blade as changed, besides, the side rubber need to be extended 1-inch thickness with a 1.5 inch radius, therefore, A special design for bottom blade shown below:

TABLE XXXII: DESIGN GEOMETRY FOR BLADE CORNER

corner design	Design Geometry
	
	

G.4 Design Sample Calculation

The blade can be assumed as a point load is applied to a hollow beam with one end fixed (assumption is shown below in Figure 50). A sample calculation for middle blade beam is shown below. The stress and displacement can be calculated based on the following equation.

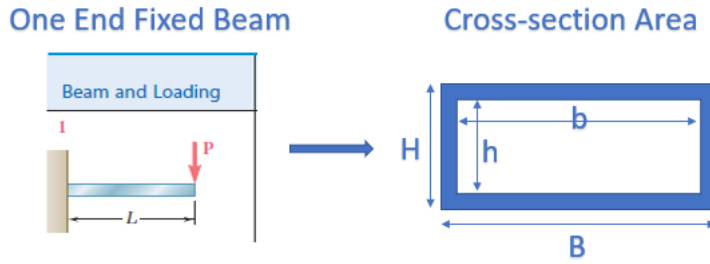


Figure 50: Assumption of Beam Section [36]

TABLE XXXIII: EQUATION SELECTED FOR DESIGN CALCULATION

Calculation	Equation	
Maximum shear stress	$\frac{3V}{2A}$	
Maximum bending stress	$-\frac{My}{I}$ where $I = \frac{BH^3}{12} - \frac{bh^3}{12}$	
Maximum deflection	$-\frac{PL^3}{3EI}$	

From the equation, it indicates that the bending stress and deflection decrease as I-moment of inertia increases.

$$I_x = \frac{BH^3}{12} - \frac{bh^3}{12} = 0.078; \quad I_y = \frac{HB^3}{12} - \frac{hb^3}{12} = 0.0255$$

From the above calculation, it tells that the horizontal orientation results in a larger number of moment of inertia. Therefore, the frame of the blade is installed in horizontal orientation. However, in order to have enough space for bottom scraper mounting on the bottom blade. The orientation of bottom blade cross-section is vertical. All the FEA results are shown in Appendix F.

Appendix H: Bottom Scrapper Detail Design Concept

Two design concepts were taken into consideration when designing the scrapper to scrap the propellant from the bottom of the mixing bowl. The first design is straight scrapper and the second design is inclined scrapper design. An Illustration for both design is shown below:

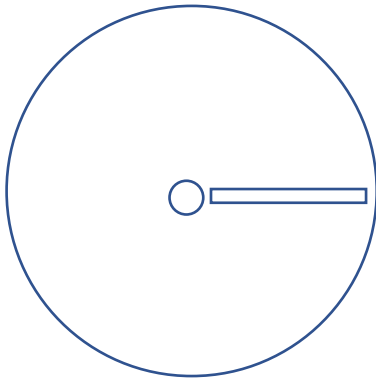


Figure 52: Straight Scrapper Design

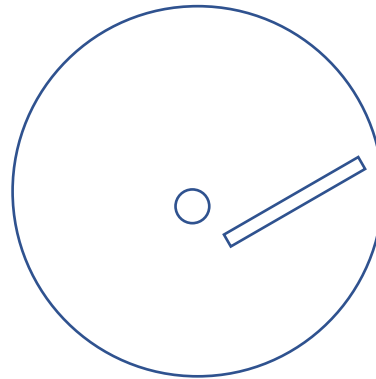


Figure 51: Inclined Scrapper Design

The straight scrapper design consists of 90 deg scrapper which will scrap the propellant as it rotates at motor rpm. The inclined scrapper will be tilted to some degree (will be determined later) with respect to the neutral horizontal axis. These designs concepts were generated by team in brainstorming session. Both designs have pros and cons which are summarized below:

TABLE XXXIV: COMPARISON BETWEEN STRAIGHT AND INCLINED SCRAPER

Straight Scrapper	Inclined Scrapper
<p>Pros:</p> <ul style="list-style-type: none"> Easy to scrap the propellant from the bottom Easy to mount on the side scrapper Requires single arms to scrap the propellant Provides uniform load to side scrapper 	<p>Pros:</p> <ul style="list-style-type: none"> Easy to scrap the propellant from the bottom Guides the propellant towards the center of the mixing bowl
<p>Cons:</p> <ul style="list-style-type: none"> Relies on water pressure to guide the propellant towards the center 	<p>Cons:</p> <ul style="list-style-type: none"> Provides a point load to side scrapper Difficult to mount on the side scrapper

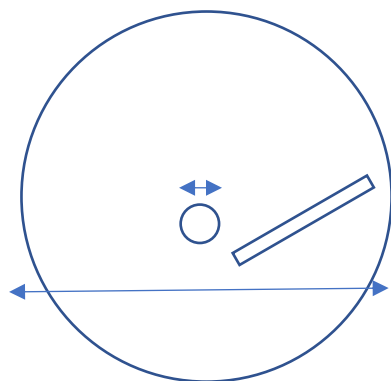
Since guiding the propellant towards the center of the mixing bowl is one the vital component of the bottom cleaning, inclined scrapper was selected over the straight scrapper.

H.1 Degree Selection:

Since inclined scrapper design was selected, a proper degree of inclination is to be determined. The degree of inclination depends on the weight attributed to scrapping of the bottom versus guiding it towards the center. Less degree (<45) of inclination scraps the propellant more than to guide it towards the center. Degree on inclination greater than 45 will guide the propellant towards the center of the mixing bowl more than scrapping it from the bottom. Hence, the team agreed to use 45 deg of inclination as both attributes are equally important for cleaning the bottom of the mixing bowl.

Number of scrapper arms, location and its orientation:

One of the key factors considered was the number of arms to perform this operation. Less number of arms means more condensed load on the side plate whereas a greater number of arms means much more distributed load. The minimum length of the scrapper for 45-degree inclined design can be determined by the following equation.



$$L (\cos(45)) = \frac{D - d}{2}$$

where
D is the diameter of bottom
d is the diameter of the exit ho

Figure 53: Inclined Scrapper Design

The total length of the scrapper found the equation above is 43.133 inches. The length obtained is too huge compared with diameter of the mixing bowl. Also, one scrapper is not feasible as it creates point load on the side wall scrapper for all the propellant scrapped from the bottom. Hence in order to solve this problem the number of scrapers can increased in

order to have distributed load and the length of each scrapper will be reduced. The number of the scrapers were varied, and the corresponding length were obtained which is summarized in the table below.

TABLE XXXV: SCRAPER LENGTH

Number of scrapers	Length
1	43.1
2	21.6
3	14.4
4	10.8
5	8.6

Since the rotation of our design is very low less number of scrapers is the most feasible option, hence 2 and 3 number of scrapers were chosen for further analysis and design approach.

Two Arm Design vs Three Arms Design

In the two arm design concept each arm length is 21.6 in, whereas in the three arms design each arms is 14.4 inch. An illustration for both design is shown below:

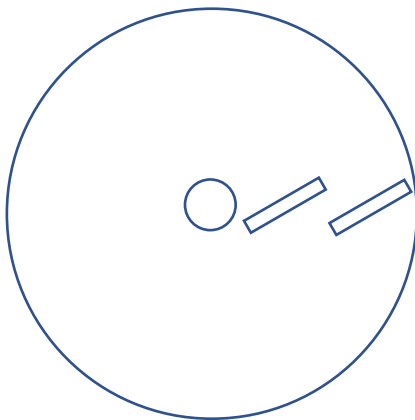


Figure 55: 21.6" arm design concept1

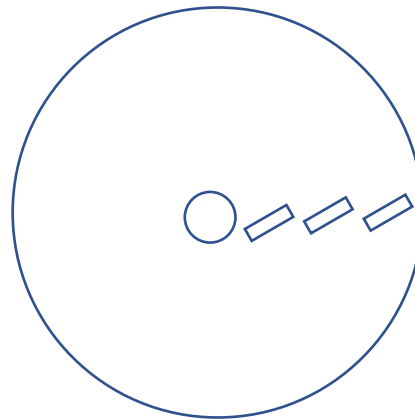
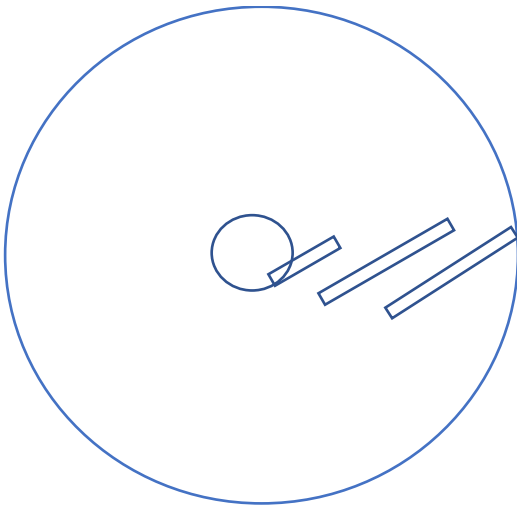


Figure 54: 14.4" arm design concept 2

was determined that both options are not suitable and poses two major flaws. The first problem is guiding the propellant towards the center as the edge of the blade is still inside of the bottom surface and in the end, propellant will be sitting

on the bottom surface. The second flaw is the gap between each blade as rotates in the circular motion. Much of the propellant will be left in the middle hence bottom will not be cleaned. After brainstorming, the team agreed to 30% overlap between consecutive plate and length and distance can be altered so the propellant is guided in the center of the hole. After discussion, the team decided to have 2 full blade and 1 half blade that will guide the propellant towards the center. Hence, the following image provides an illustration for the concept design for further analysis:



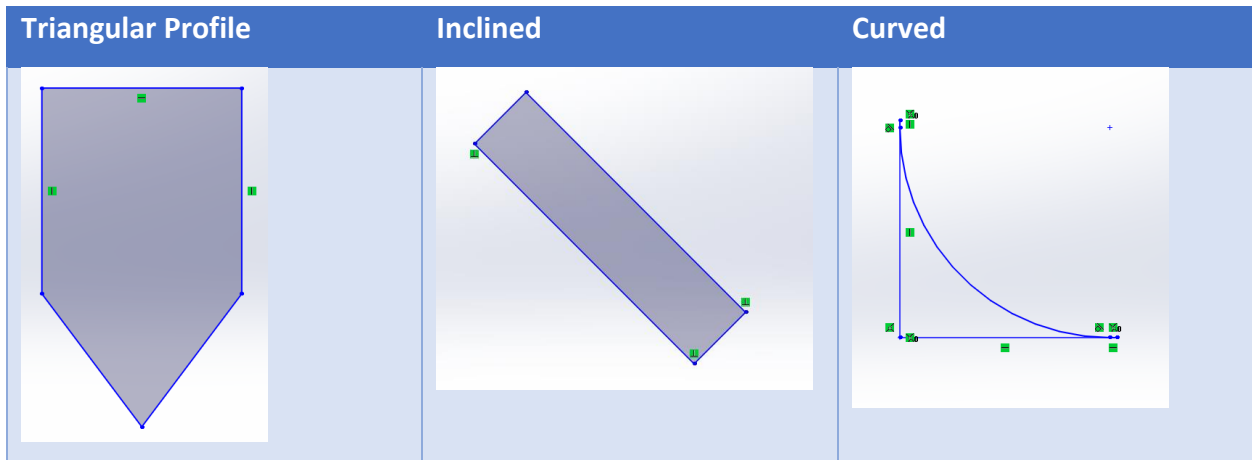
$$(1 + 0.7 + 0.2)L (\cos(45)) = \frac{D - d}{2} + 1$$

Figure 56: Finalized design orientation

In order to provide some clearance for the main shaft it was determined the only 1-inch part is required for the most inner plate to hang inside the hole. Solving for the above equation 19.47 inch was obtained. In order to have better design parameter it was decided to have two of the 20-inch arm and one of the 10-inch arm. At this point number of arms and its location with respect to the central axis has been determined. The next phase is to determine the number

3 different shapes were brainstormed in the team and following is the side view of them:

TABLE XXXVI: SIDE VIEW PROFILE



The three profiles were analyzed for the scrapper for our design. All these profile were aimed to scrap the propellant as fast as possible as much efficiently as possible. After looking for off the shelf parts for the scrapper, it was concluded that triangular and curved profile are not common and were very hard to source. The tip of triangular profile will be wearing constantly hence it will be very hard to make sure that it will be contact always. The curved profile is very difficult to mount and provide necessary support while it is scrapping the propellant. The inclined profile was chosen as the best candidate for the bottom cleaning of the bowl as it is easy to source, mount, provide necessary support and ensure that that is it always in contact with the bowl.

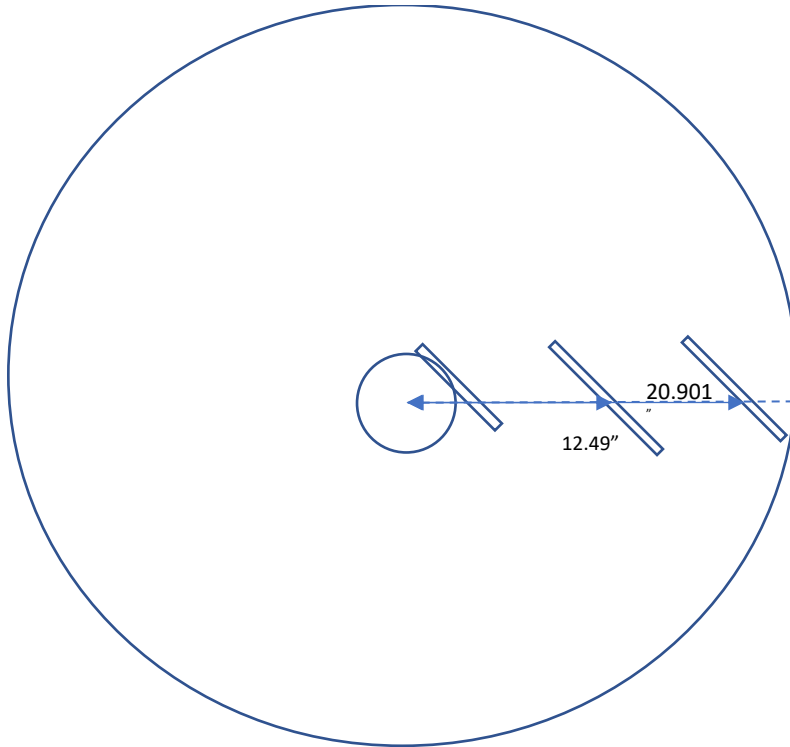


Figure 57: Geometry of Side Scraper

H.2 Material Selection:

This section will discuss 4 material chosen for the bottom scrapper design. The material were analyzed and evaluate on the ability of static dissipation, temperature, chemical resistance, rigidity, easy to source and cost. Each attribute were evaluated using criteria importance weighing and all these attributes were identified as crucial for the proper functioning.

TABLE XXXVII: IMPORTANCE CRITERIA MATRIX

Criteria	A) Static Dissipating	B) Temperature	C) Chemical Resistant	D) Rigidity	E) Easy to Source	F) Cost
A) Static Dissipating	-	A	A	A	A	A
B) Temperature	-	-	C	B	B	B

TABLE XXXVI: IMPORTANT CRITERIA MATRIX (Continued)

Criteria	A) Static Dissipating	B) Temperature	C) Chemical Resistant	D) Rigidity	E) Easy to Source	F) Cost
C) Chemical Resistant	-	-	-	C	C	C
D) Rigidity	-	-	-	-	D	D
E) Easy to Source	-	-	-	-	-	E
F) Cost	-	-	-	-	-	-
Weight	0.33	0.2	0.27	0.13	0.07	0

The materials considered for bottom scrapper are neoprene, foam rubber, silicone and Ultra-strength neoprene rubber. Based on the research on material property, following table was created and to identify the quality of the material.

Excellent – 5; Very Good – 4; Good – 3; Average – 2; Poor – 1.:

TABLE XXXVIII: MATERIAL COMPARISON

	Neoprene	Foam Rubber	Silicone	Neoprene Rubber
A) Static Dissipating	5	5	4	5
B) Temperature	4	4	5	4
C) Chemical Resistant	3	4	3	5
D) Rigidity	5	2	2	5
E) Easy to Source	3	4	4	3
F) Cost	4	4	4	3

A weighted decision matrix was then created in order to chose best material for our application.

TABLE XXXIX: WEIGHTED DECISION MATRIX

		Neoprene	Foam Rubber	Silicone	Neoprene Rubber
A) Static Dissipating	0.33	5	5	4	5
B) Temperature	0.2	4	4	5	4
C) Chemical Resistant	0.27	3	4	3	5
D) Rigidity	0.13	5	2	2	5
E) Easy to Source	0.07	3	4	4	3
F) Cost	0	4	4	4	3
Total		4.12	4.07	3.67	4.66

The results showed that ultra strength neoprene rubber is the best material for the application.

Appendix I: Finite Element Analysis

The detailed design is described in this section including the force and stress analysis using analytical method and the frequency analysis is also done to avoid resonance situation happen during the operation.

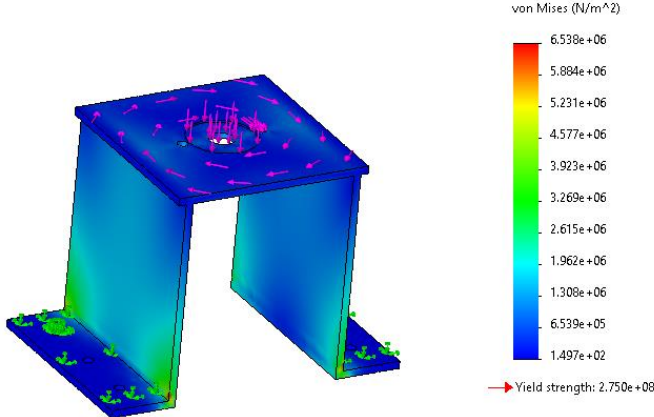
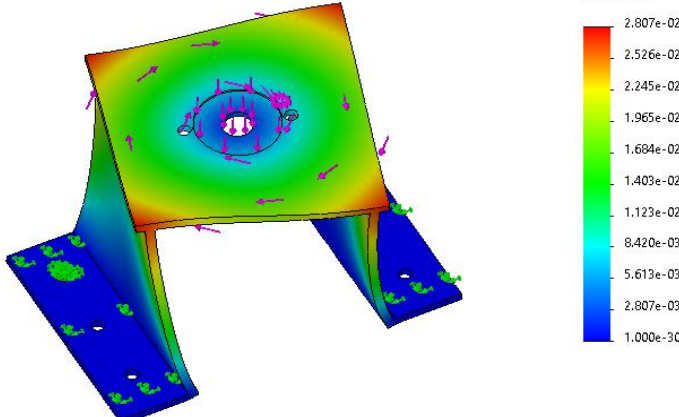
I.1 Static Analysis

The static analysis is to verify the stress of the object is under the safety of factor of two of its yield strengths. Also, displacement should also be in a reasonable range during the operation.

I.1.1 Mounting Plate

The Mounting Plate is experiencing a torque of 280 Nm. and a weight of 13lb acting on itself.

TABLE XL: FEA ANALYSIS FOR MOUNTING PLATE

Analysis	Results
Max Strength	 <p>von Mises (N/m²)</p> <ul style="list-style-type: none"> 6.538e+06 5.884e+06 5.231e+06 4.577e+06 3.923e+06 3.269e+06 2.615e+06 1.962e+06 1.308e+06 6.539e+05 1.497e+02 <p>→ Yield strength: 2.750e+08</p>
Max displacement	 <p>URES (mm)</p> <ul style="list-style-type: none"> 2.807e-02 2.526e-02 2.245e-02 1.965e-02 1.684e-02 1.403e-02 1.123e-02 8.420e-03 5.613e-03 2.807e-03 1.000e-03

1.1.2 Lid

Scenario 1: The lid is lifted up through three eye bolts and the lid will need to experience the weight of mechanical scraping system and pressurized water system.

Scenario 2: The lid is fixed on the mixing bowl while the mechanical scraping system is rotating.

TABLE XLI: FEA ANALYSIS FOR LID (SCENARIO 1)

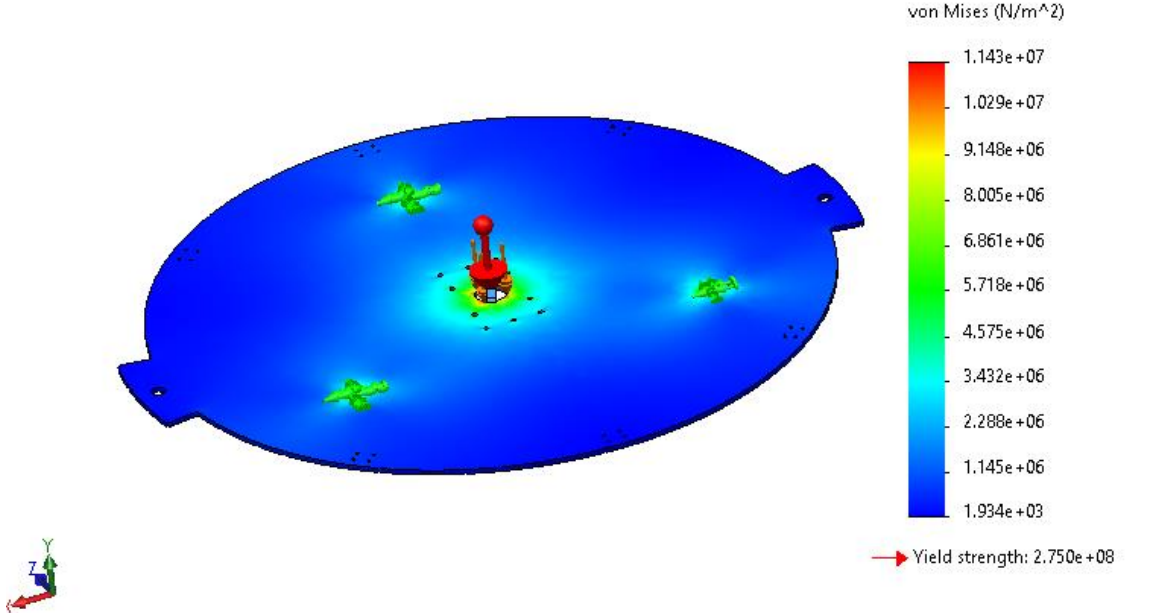
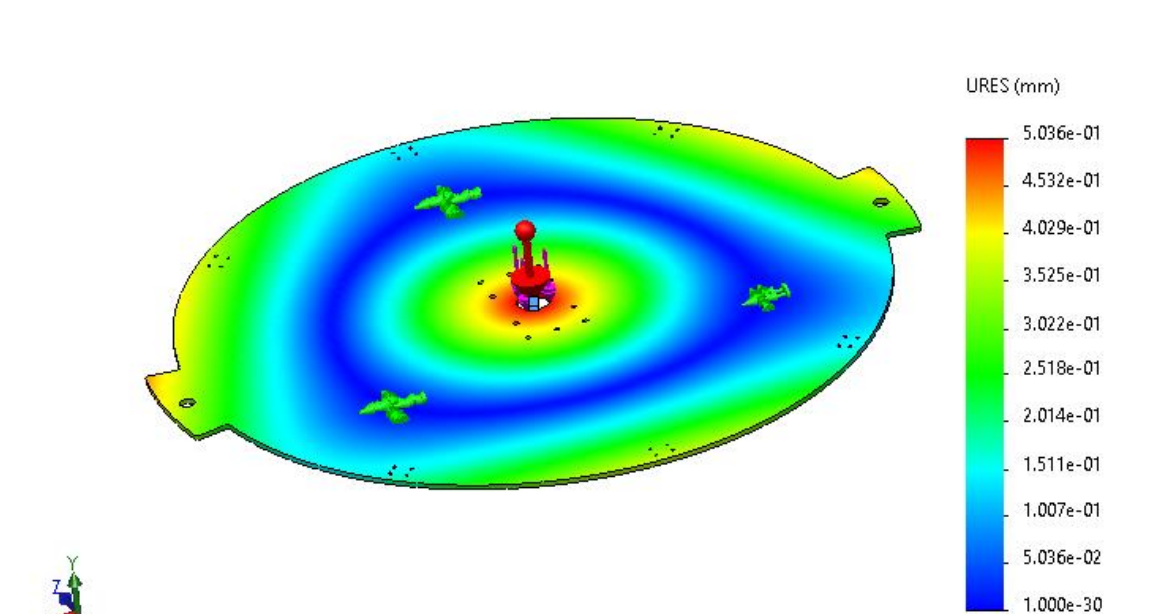
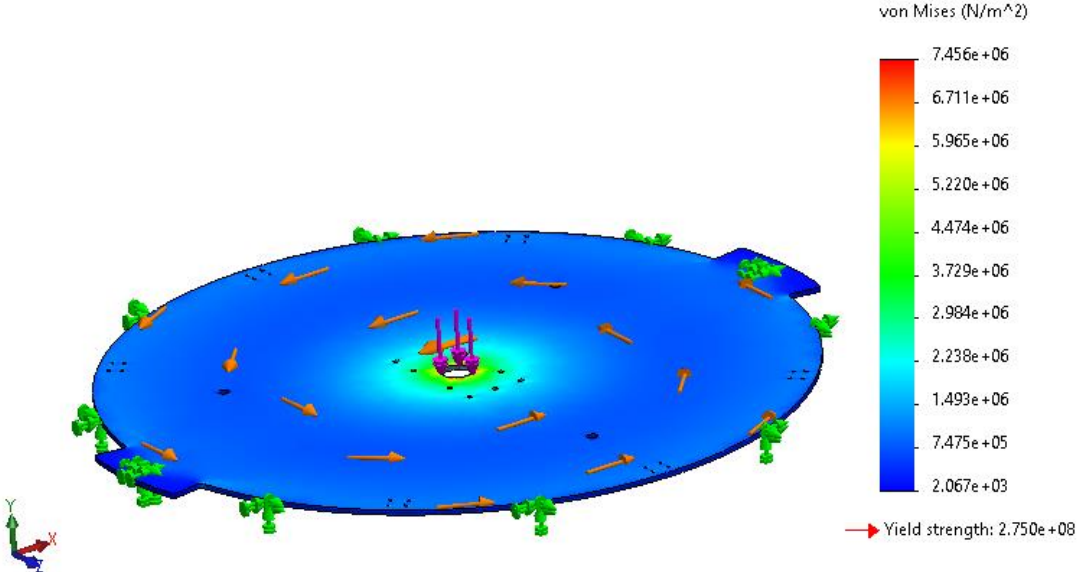
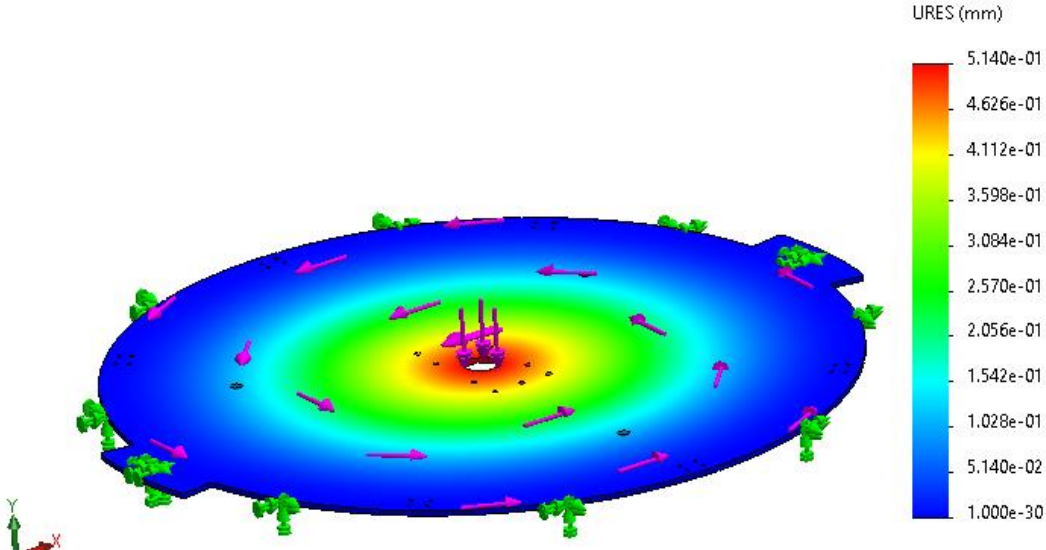
Analysis results	Results (scenario 1)
<p>Max Strength</p>	 <p>von Mises (N/m²)</p> <ul style="list-style-type: none"> 1.143e+07 1.029e+07 9.148e+06 8.005e+06 6.861e+06 5.718e+06 4.575e+06 3.432e+06 2.288e+06 1.145e+06 1.934e+03 <p>→ Yield strength: 2.750e+08</p>
<p>Max displacement</p>	 <p>URES (mm)</p> <ul style="list-style-type: none"> 5.036e-01 4.532e-01 4.029e-01 3.525e-01 3.022e-01 2.518e-01 2.014e-01 1.511e-01 1.007e-01 5.036e-02 1.000e-30

TABLE XLII: FEA ANALYSIS FOR LID (SCENARIO 2)

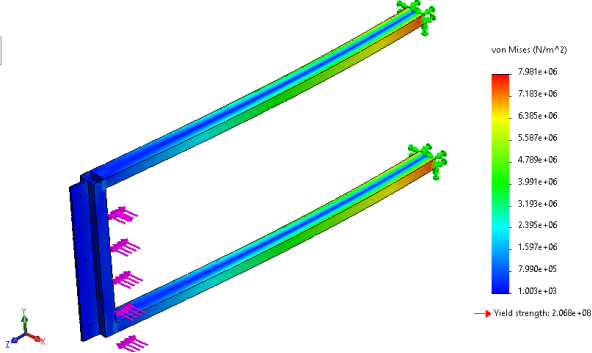
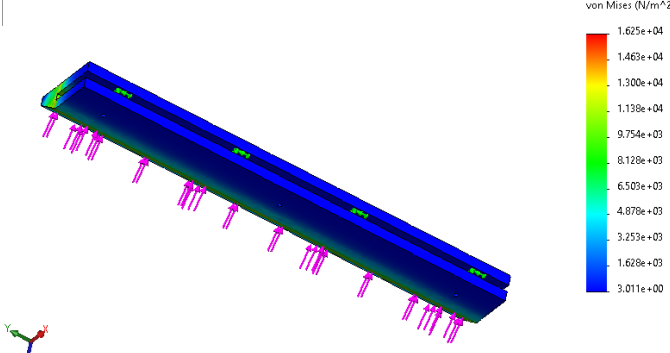
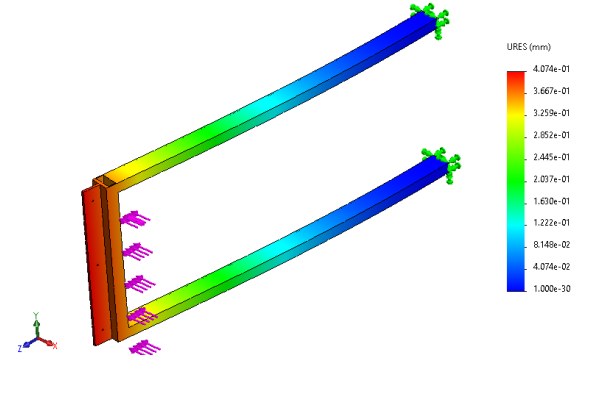
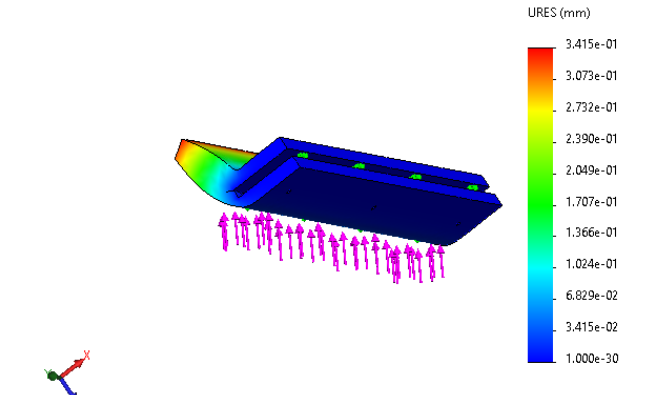
Analysis results	Results (scenario 2)
Max Strength	 <p>von Mises (N/m²)</p> <ul style="list-style-type: none"> 7.456e+06 6.711e+06 5.965e+06 5.220e+06 4.474e+06 3.729e+06 2.984e+06 2.238e+06 1.493e+06 7.475e+05 2.067e+03 <p>→ Yield strength: 2.750e+08</p>
Max displacement	 <p>URES (mm)</p> <ul style="list-style-type: none"> 5.140e-01 4.626e-01 4.112e-01 3.598e-01 3.084e-01 2.570e-01 2.056e-01 1.542e-01 1.028e-01 5.140e-02 1.000e-30

I.1.3 Scraping Blades and Rubber scraper

The blade and rubber scraper are experiencing a force pushed by residual propellant on the inner surface. The distributed force is assumed 0.75lb/in that applied to the surface.

I.1.3.1 Top Blades and Rubber Scraper

TABLE XLIII: FEA ANALYSIS FOR TOP BLADE AND RUBBER SCRAPER

Analysis results	Results	
Max Strength	 <p>von Mises (N/m²)</p> <ul style="list-style-type: none"> 7.981e+06 7.183e+06 6.385e+06 5.587e+06 4.789e+06 3.991e+06 3.193e+06 2.395e+06 1.597e+06 7.990e+05 1.003e+03 <p>→ Yield strength: 2.068e+08</p>	 <p>von Mises (N/m²)</p> <ul style="list-style-type: none"> 1.625e+04 1.463e+04 1.300e+04 1.138e+04 9.754e+03 8.128e+03 6.503e+03 4.878e+03 3.253e+03 1.628e+03 3.011e+00
Max displacement	 <p>URES (mm)</p> <ul style="list-style-type: none"> 4.074e-01 3.667e-01 3.259e-01 2.852e-01 2.445e-01 2.037e-01 1.630e-01 1.222e-01 8.148e-02 4.074e-02 1.000e-30 	 <p>URES (mm)</p> <ul style="list-style-type: none"> 3.415e-01 3.073e-01 2.732e-01 2.390e-01 2.049e-01 1.707e-01 1.366e-01 1.024e-01 6.829e-02 3.415e-02 1.000e-30

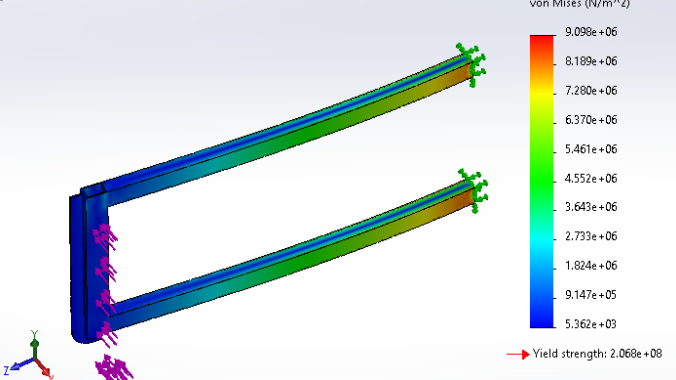
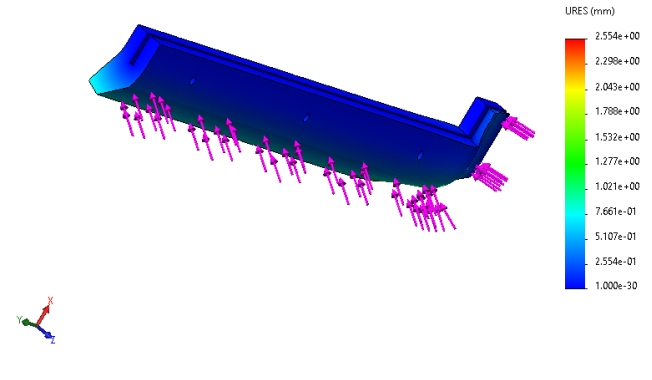
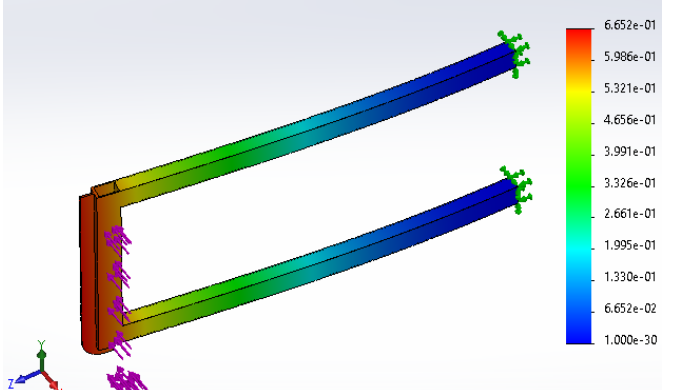
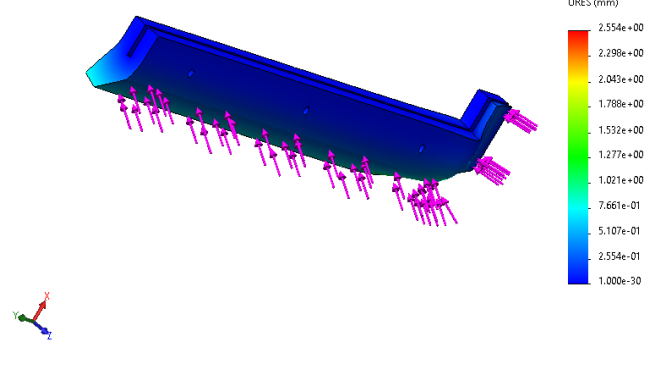
I.1.3.2 Middle blades and rubber scraper

The similar result happened as the results of top blades and rubber scraper.

I.1.3.3 Bottom blades and rubber scraper

The blade and rubber scraper are experiencing a force pushed by residual propellant on the inner surface with 0.75lb/in.

TABLE XLIV: FEA ANALYSIS FOR BOTTOM BLADE AND SCRAPER

Analysis	Results	
Max Strength	 <p>von Mises (N/m²)</p> <p>9.098e+06 8.189e+06 7.280e+06 6.370e+06 5.461e+06 4.552e+06 3.643e+06 2.733e+06 1.824e+06 9.147e+05 5.362e+03</p> <p>Yield strength: 2.068e+08</p>	 <p>URES (mm)</p> <p>2.554e+00 2.298e+00 2.043e+00 1.788e+00 1.532e+00 1.277e+00 1.021e+00 7.661e-01 5.107e-01 2.554e-01 1.000e-30</p>
Max displacement	 <p>URES (mm)</p> <p>6.652e-01 5.986e-01 5.321e-01 4.656e-01 3.991e-01 3.326e-01 2.661e-01 1.995e-01 1.330e-01 6.652e-02 1.000e-30</p>	 <p>URES (mm)</p> <p>2.554e+00 2.298e+00 2.043e+00 1.788e+00 1.532e+00 1.277e+00 1.021e+00 7.661e-01 5.107e-01 2.554e-01 1.000e-30</p>

1.1.3.4 Bottom blades and rubber scraper

The bottom base scrapper consist of 4, 20 inch arm scrapper rubber assembly and 2, 10 inch arm scrapper rubber asseby. The 20 inch arm scrapper and rubber were analyzed with 10 lbs force and 10inch arm scrapper and rubber with 5 lbs force. Following results were obtained:

TABLE XLV: FEA ANALYSIS 10 INCH ARM SCRAPPER

Analysis	Results
Max Strength	<p>von Mises (N/m²)</p> <ul style="list-style-type: none"> 1.705e+07 1.534e+07 1.364e+07 1.193e+07 1.023e+07 8.523e+06 6.819e+06 5.114e+06 3.409e+06 1.705e+06 2.260e+00 <p>→ Yield strength: 1.724e+03</p>
Max displacement	<p>URES (mm)</p> <ul style="list-style-type: none"> 9.809e-03 8.828e-03 7.847e-03 6.866e-03 5.885e-03 4.904e-03 3.923e-03 2.943e-03 1.962e-03 9.809e-04 1.000e-03

TABLE XLVI: FEA ANALYSIS 20 INCH ARM SCRAPPER

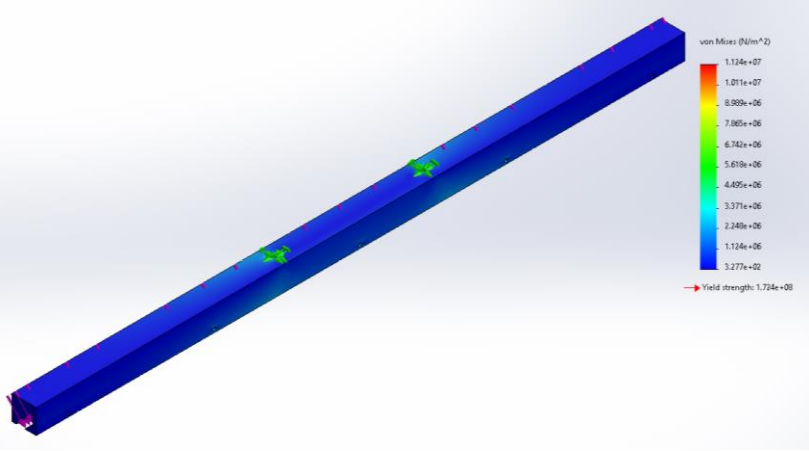
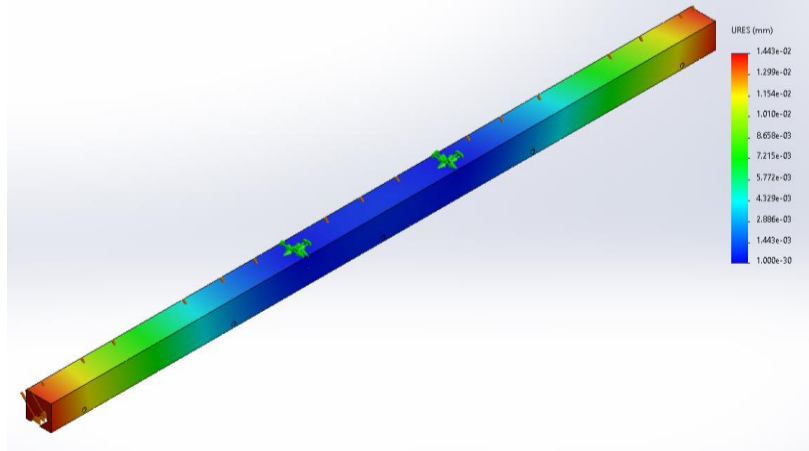
Analysis	Results
<p>Max Strength</p>	
<p>Max displacement</p>	

TABLE XLVII: FEA ANALYSIS 20 INCH RUBBER

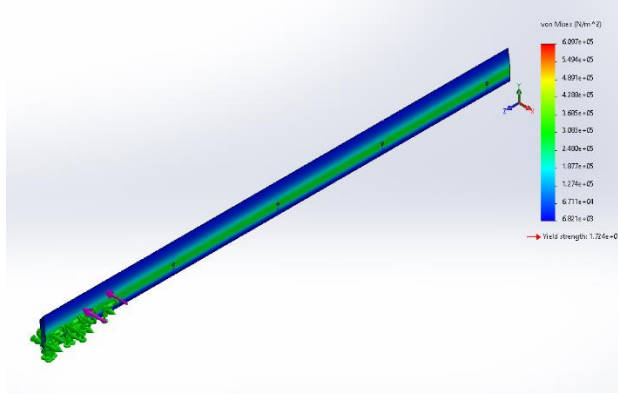
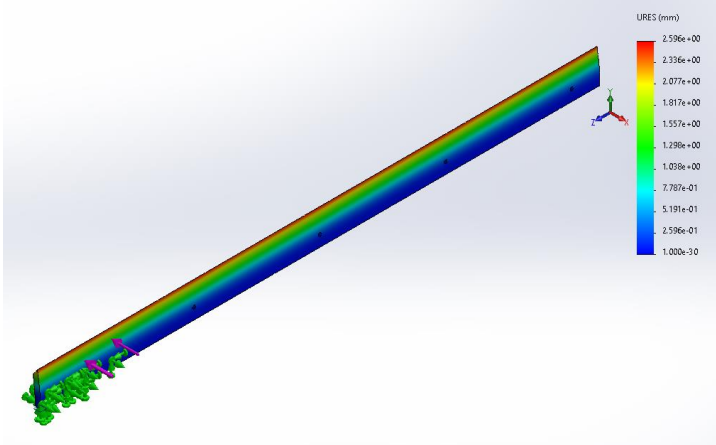
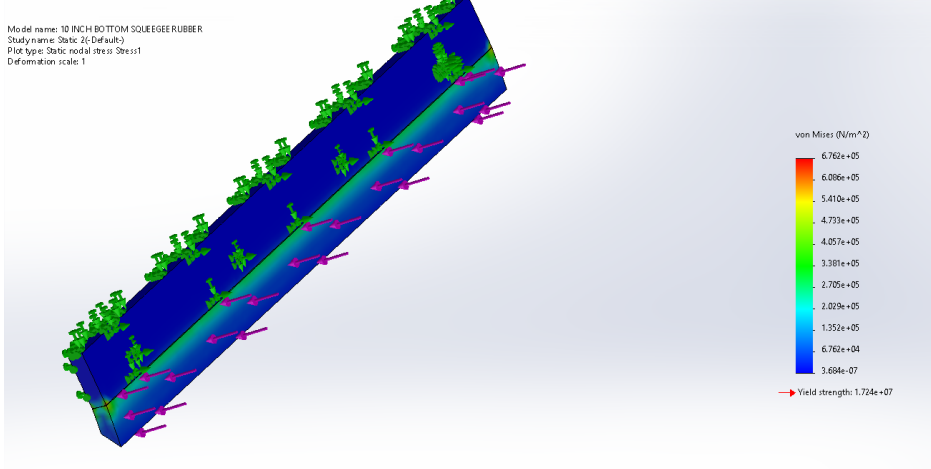
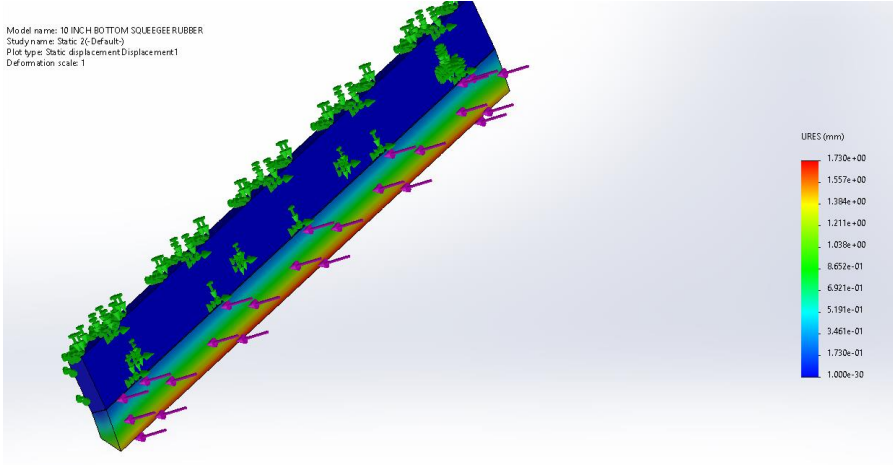
Analysis	Results
<p>Max Strength</p>	 <p>FEA stress analysis plot showing von Mises stress distribution. The legend indicates values in N/m^2, ranging from 6.921×10^0 to 6.000×10^5. A red arrow points to a value of 1.724×10^7 labeled "Yield strength".</p>
<p>Max displacement</p>	 <p>FEA displacement analysis plot showing URES (mm) distribution. The legend indicates values in mm, ranging from 1.000×10^0 to 2.536×10^0.</p>

TABLE XLVIII: FEA ANALYSIS 10 INCH RUBBER

Analysis	Results
<p>Max Strength</p>	 <p>Model name: 10 INCH BOTTOM SQUEEGEE RUBBER Study name: Static 2(-Default) Plot type: Static nodal stress Stress1 Deformation scale: 1</p> <p>von Mises (N/m²)</p> <p>Yield strength: 1.724e+07</p>
<p>Max displacement</p>	 <p>Model name: 10 INCH BOTTOM SQUEEGEE RUBBER Study name: Static 2(-Default) Plot type: Static displacement Displacement1 Deformation scale: 1</p> <p>URES (mm)</p>

I.2 Frequency analysis

The frequency analysis is to verify the motor stand will not have resonance during the operation. The resonance result will not happen as long the amplitude of frequency of each mode shape is not the same as natural frequency

I.2.1 Motor stand

The following table indicate the natural frequency at each mode shape and all the frequency should be above the motor speed which is 0.733 rad/s. Therefore, at this current speed, the resonance will not happen.

TABLE XLIX: MODE SHAPE OF MOTOR STAND

Mode shape	Natural frequency (Rad/Sec)
1	619.48
2	1657.1
3	1784.9
4	2701.7
5	3411.4

Appendix J: Detail Cost Analysis

This section provides details on the cost of each main component in more details that is Teflon coating application, hydraulic system, Mechanical components and Pressurized water system. The parts that were unable to receive a quote were estimated based off similar parts from off shelf parts. The total cost for all components is organized in the table below. The parts that were estimated have an asterisk (*) to denote the estimated cost.

J.1 Cost for Teflon Coating

The cost of the Teflon coating was calculated based on the information provided by the client. List of parameters provided by the client are mentioned below [37]

1. The same Teflon coating was performed on a subscale mixer with diameter 14.5 inch and height was assumed to be 2 inches.
2. The cost of the coating was 150\$ in year 2010

Based on this information this information the surface area of the Teflon coating for the follower plate was calculated as 421.37 in^2 assuming the coating was done on entire surface from this the cost for Teflon coating per surface area was calculated as $0.36 \text{ \$/in}^2$.

The surface area for the propellant mixing bowl have a diameter of 64 inches and height of 45 inches based on this the surface area for the propellant mixing bowl was calculated as 12264.8 in^2 considering the Teflon coating will be performed on bottom and sides of the propellant mixing bowl. Therefore, the total price for the Teflon coating was identified to be 4366.08 in year 2010 with an average inflation rate of 1.50 % the price for Teflon coating in todays date was calculated as 5068.37\$ as shown in Figure 58 below.

Inflation from 2010 to 2020

Cumulative price change	16.09%
Average inflation rate	1.50%
Converted amount (\$4,366.08 base)	\$5,068.37
Price difference (\$4,366.08 base)	\$702.29
CPI in 2010	117.500
CPI in 2020	136.400
Inflation in 2010	2.35%
Inflation in 2020	2.25%

Figure 58: Price for Teflon coating in todays date [38]

J.2 Cost for Hydraulic System

The hydraulic system consists of Geroller motor and Hydralic power pack. The quote for the hydraulic motor was provided by Dynamic machining as shown in Figure 59 below and quoted as 14000\$ for a geroler motor and the hydraulic power pack.



Tomas Zeljko <Tomas@dynamicmachinecorp.com>
Mon 12/7/2020 4:22 PM
To: Arvinder Saini



Hi Arvinder,
Our best estimate is \$13,000.00-\$14,000.00. Explosion proof valve alone is almost \$7500.00. Everything else is not that expensive.
We didn't get all prices from our vendors, so this is an estimate
Regards
Tomas

Figure 59: Quote on a Hydraulic motor and power pack provided by Dynamic Machining [39]

J.4. Cost for Pressurized Water System

The pressurized water system consists of number of parts that are easily available from McMaster carr as shown in TABLE L below. A miscellaneous cost of 20% Is added onto the total

amount to account for installation cost and any inflation in price from USD to CAD. All the prices mentioned in total cost are in USD which was later converted to CAD with using a current exchange rate of 1.30 CAD which is equivalent to 1 USD. The sub total also includes the 12% total tax based on Manitoba tax rates.

TABLE L: COST FOR THE PRESSURIZED WATER SYSTEM

	Pressurized water system	Source	Part Number	Qty	Total Cost
Water System	SST ¼" Pipe 18" Length	McMaster Carr	48395K42	1	35.2
	SST ¼" Pipe 12" Length	McMaster Carr	46755K112	4	110.48
	SST ¼" Pipe 20" Length	McMaster Carr	48395K623	4	156.56
	SST ¼" Pipe 8" Length	McMaster Carr	46755K82	2	38.36
	SST ¼" Pipe 6" Length	McMaster Carr	46755K72	2	29.02
	HP Cross Connector	McMaster Carr	4443K652	4	172.96
	HP Tee Connector	McMaster Carr	4443K642	5	111
	HP 45° Elbow Connector	McMaster Carr	4443K622	12	315.84
	HP Straight Adapter	McMaster Carr	4443K662	4	26.24
	HP 90° Elbow Connector	McMaster Carr	4443K612	4	74.84
	¼ NPT x ¼ BSPP Adapter	McMaster Carr	4822T339	1	17.13
	¼ BSPP Reducer	McMaster Carr	51205K754	1	72.04
	¼ Fully Threaded Nipple	McMaster Carr	46755K12	1	4.5
	¼ NPT Reducer	McMaster Carr	4822T337	1	39.81
	¼ 65° Flat Spray Nozzle	McMaster Carr	3234K251	12	103.44
	¼ Solid Spray Nozzle	McMaster Carr	3234K246	2	19.4
	Swivel Joint	Tameson	FI2EMF-SFP-014G-R	1	356.1
		20% Miscellaneous			
				Sub Total	2261.844

J.5. Cost for Mechanical Component

In order to calculate the total price of the mechanical component it was divided into two parts: purchase parts and manufacturing parts as shown in TABLE LI and Table LII

TABLE LI: COST FOR MECHANICAL PURCHASED PARTS

Off Market Mechanical Components		Source	Part Number	Qty	Total Cost
(Side Scraper)	Top and Middle Blade T Bar	McMaster Carr	1352T12	1 (6 ft. Lg.)	187.6
	Top and Middle Blade Rectangular Tube	McMaster Carr	89825K56	3 (6 ft. Lg.)	198.84
	Bottom Blade T Bar	McMaster Carr	1352T11	1 (3 ft. Lg.)	105
	Bottom Blade Rectangular Tube	McMaster Carr	89825K23	3 (6 ft. Lg.)	40.69
Hardware	1.5-inch Dowel pin	McMaster Carr	98306A907	2	88.42
	Cotter Pin (3/16)	McMaster Carr	98355A245	2	13.9
	Socket head Capscrew(5/16-18 Thread Size)	McMaster Carr	92185A578	24	11.34
	Hex Head Fastner(5/8-11)	McMaster Carr	92186A804	4	7.36
	USS Washer	McMaster Carr	93852A138	4	11.88
	Lifting Bolt	McMaster Carr	3059T750	3	546.45
	Lifting Nut	McMaster Carr	94805A247	3	25.74
	O ring(Dash Number - 152)	McMaster Carr	9452K173	1	10.46
	Retaining Ring (3inch Dia)	McMaster Carr	91590A185	1	22.73
	Set Screw	McMaster Carr	94355A535	1	4.66
	Top and middle blades Screws	McMaster Carr	92314A115	12	97.44
	Top and middle blades Washers	McMaster Carr	92844A121	12	45.24
	Top and middle blades Nuts	McMaster Carr	90257A005	12	67.92
	Bottom Screws	McMaster Carr	91720A249	6	41.04
	Bottom Washers	McMaster Carr	90107A011	6	21.84
	Bottom Nuts	McMaster Carr	90257A011	6	43.74
Other Mechanical Component	Hold Down Toggle Clamp (Holding Capacity: 750 lbs)	McMaster Carr	51325A64	6	447.66
	Mounted Roller Bearing	McMaster Carr	1498N16	1	659.89
	Mounting Plate for (Motor)	McMaster Carr	8896K24	1	475.98
	Hub	McMaster Carr	3565N8	2	218.7
	Split Spider	McMaster Carr	3565N47	1	40.95
	Steel Spider Cover	McMaster Carr	3565N63	1	41.96
TOTAL COST IN CAD					5063.138

Table LII: COST FOR MANUFACTURE PARTS

	Custom Made Machined / Welded Parts	Source	Part Number	Cost	Qty	Total Cost
Mfg. Cost	Rubber Scraper(Side, Middle, Bottom)	Argus	08,09,10,12,07,	17000	1	17000
	10 inch arm bottom scraper (Labor)	Standard Machine Work	11	300	2	600
	20 inch arm bottom scraper (Labor)	Standard Machine Work	13	400	4	1600
	Bottom Blade Assy (Weld)	Standard Machine Work	Sub Assy 3-2	200	2	400
	Bottom Blade Bracket (Labor)	Standard Machine Work	13	300	2	600
	Bottom Blade Bracket (Material)	Standard Machine Work	13	100	2	200
	T bar(Welding to blades)	Standard Machine Work	Sub Assy 3-1, 3-2,3-3	200	6	1200
	Middle and top Blade T bar(Labor)	Standard Machine Work	1352T11_Cut to length	50	4	200
	Motor Mount Assy weld	Standard Machine Work	1	490	1	490
	Upper mounting plate (Labor)	Standard Machine Work	1-1'	200	1	200
	Upper mounting plate (Material)	Standard Machine Work	1-1'	50	1	50
	Gusset (Labor)	Standard Machine Work	1-2'	100	1	100
	Gusset (Material)	Standard Machine Work	1-2'	60	1	60
	Bottom mounting plate (Labor)	Standard Machine Work	1-3'	50	1	50
	Bottom mounting plate (Material)	Standard Machine Work	1.-3'	50	1	50
	Side Mounting Plate (Labor)	Standard Machine Work	1-4'	49	1	49
	Side Mounting Plate (Material)	Standard Machine Work	1-4'	50	1	50
	Sleeve for Hydraulic Motor (Labor)	Standard Machine Work	3	250	1	250
	Sleeve for Hydraulic Motor (Material)	Standard Machine Work	3	138.62	1	138.62
	Coupling for Transmission shaft (Labor)	Standard Machine Work	4	75	1	75
	Coupling for Transmission shaft (Material)	Standard Machine Work	4	138.62	1	138.62
	Lid*	Guestimate	6	1500	1	1500
	Funnel *	Guestimate	14	500	1	500
	Flange*	Guestimate	16	800	1	800

TABLE LI: COST FOR MANUFACTURING PARTS (Continued)

Custom Made Machined / Welded Parts	Source	Part Number	Cost	Qty	Total Cost
Weld assembly for (Shaft and blades) *	Guestimate	17	1200	1	1200
L Bracket (Sub Assy 4-2) *		13	200	6	1200
Miscellaneous cost (10%) and (12% tax)					6314.273
Total Cost of Mechanical Components					34751.51

All the values above with * refers to the guestimate values.

Appendix K: General Risk Analysis

K.1 General Risk Management

The risk management plan is a procedure used to manage any risks that the team or project might encounter during the project. By identifying and analyzing the risks, a risk response plan is developed to respond to all the potential risks that might occur.

K.1.1 Risk Identifications and Description

Updated risk identifications and descriptions is shown below to indicate potential risks of top 2 design concepts generated after design screening and scoring. The risks were ranked based on the date team registered each risk and categorized by safety, budget, quality and schedule. The new risks are categorized by design concept as shown in **Error! Reference source not found.** table below.

TABLE LIII: UPDATED RISK IDENTIFICATION AND DESCRIPTION

Risk Number	Date Registered	Risk Category	Risk Description
1	20-09-16	Safety	Explosive safety and environmental issues will cause danger to the environment and to the operators
2	20-09-16	Budget	Project exceeds the planned budget will cause dissatisfaction of the client
3	20-09-16	Quality	Operators find new process difficult to use, causes a failure of project design
4	20-09-16	Quality	Design fails to achieve client's expectations
5	20-09-16	Quality	Design is not practical to build, which will cause a disqualified project team
6	20-09-25	Schedule	Team members become sick or are unable to work, which will cause a loss of team resource and impact the plan to complete the desired tasks

TABLE LII: UPDATED RISK IDENTIFICATION AND DESCRIPTION (Continued)

Risk Number	Date Registered	Risk Category	Risk Description
7	20-09-25	Schedule	Team member not abiding to team rules will cause a delay of desired tasks
8	20-09-30	Quality	Design fails to eliminate the need for the operator to climb inside the propellant mixer bowl
9	20-10-22	Concept (Extendable Rod)	The concept design could create sparkles during mechanical scraping process
10	20-10-25	Concept (Extendable Rod)	Residual propellant cannot be cleaned completely
11	20-10-25	Concept (Extendable Rod)	Remote control or electric equipment cannot be installed in warehouse
12	20-10-29	Concept (Lubrication)	Coating may come off after multiple use
13	20-10-29	Concept (Lubrication)	Coating is too thick for tolerance between blades and the inside surface
14	20-10-29	Concept (Extendable Rod)	The scrapper cannot reach the corner of mixing bowl
15	20-10-29	Concept (Lubrication)	Hard to control excessive wear on the outer diameter during vertical scraping motion
16	20-10-29	Concept (Lubrication)	Extendable Rod may cause buckling due to high scraping force

K.1.2 Probability and Impact Matrix

Different risk has different impact on the project, so the probability rating and the impact rating decides the level of threat that each risk impose onto the project. The probability of each risk rating is described in the following table:

TABLE LIV: RISK PROBABILITY MATRIX [40]

Risk management likelihood descriptors			% likelihood
5	Almost Certain	Risk is expected to occur in most circumstances: >95% chance to occurrence	>95%
4	Likely	Risk will probably occur in most circumstances: 50-95% chance of occurrence.	50-95%
3	Unlikely	Risk might occur at some time: 25-50% chance of occurrence	25-50%
2	Rare	Risk could occur at some time: 5-25% chance of occurrence.	5-25%
1	Extremely Rare	Risk may occur only in exceptional circumstances: <5% chance of occurrence	<5%

The impact that can affect the project is given a rating on how significant of an effect it may have on a project and is described in the following table.

TABLE LV: RISK IMPACT MATRIX [40]

Risk management likelihood descriptors			% likelihood
5	Extreme	Risk will have an extreme impact on the project scope, schedule, and/or cost and may prohibit the project from proceeding. Key stakeholders must be engaged immediately.	>95%
4	Major	Risk will have a major effect on project scope, schedule, and/or cost. There is a need to engage key stakeholders before continuing with project work.	50-95%

3	Moderate	Risk will moderately affect project scope, schedule, and/or cost. Key stakeholders may need to be contacted.	25-50%
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TABLE LIV: RISK IMPACT MATRIX [40] (Continued)

Risk management likelihood descriptors			% likelihood
4	Minor	Risk may have minor impacts on project scope, schedule, and/or cost but remain within the threshold stated in the PM Plan.	5-25%
5	Insignificant	Risk will not have a measurable impact on project scope, schedule, and/or cost.	<5%

The total risk rating is then calculated by multiply the probability rating and impact rating. The results can be shown in the table below:

TABLE LVI: TOTAL RISK RANKING

Total Risk Rating	Impact				
	Insignificant	Minor	Moderate	Major	Extreme
Extremely Rare	1	2	3	4	5
Rare	2	4	6	8	10
Unlikely	3	6	9	12	15
Likely	4	8	12	16	20

Therefore, the risk rating for the project is calculated as the table shown below:

TABLE LVII: RISK RATING OF THE CHOSEN DESIGN

Risk Number	Risk Description	Probability	Impact	Total Risk Rating
-------------	------------------	-------------	--------	-------------------

9	The concept design could create sparkles during mechanical scraping process	2	5	10
10	Residual propellant cannot be cleaned completely	3	3	9
11	Remote control or electric equipment cannot be installed in warehouse	4	3	12
12	Coating may come off after multiple use	3	2	6

TABLE LVI: RISK RATING OF THE CHOSEN DESIGN

Risk Number	Risk Description	Probability	Impact	Total Risk Rating
13	Coating is too thick for tolerance between blades and the inside surface	2	3	6
14	The scrapper cannot reach the corner of mixing bowl	4	3	12
15	Hard to control excessive wear on the outer diameter during vertical scraping motion	3	2	6
16	Extendable Rod may cause buckling due to high scraping force	2	2	4

K.1.3 Risk Response Plan

The risk response plan provides a response to each risk of the top three design concepts. The risk response plan is created to tackle/deflect/mitigate the above-mentioned risks.

TABLE XIII: RISK RESPONSE PLAN

Total Risk Rating	Risk Description	Risk Number	Risk response category	Risk Response
12	Remote control or electric equipment cannot be installed in warehouse	11	Mitigate	Try to use hydraulic method or pneumatic method
12	The scrapper cannot reach the corner of mixing bowl	14	Mitigate	Scrapper can be wrapped by more elastic rubber material and apply extra force when scraping the corner

10	Explosive safety and environmental issues will cause danger to the environment and to the operators	1	Mitigate	Make a list of parts and materials compatible with propellant to avoid explosion or safety issue
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TABLE XIII: RISK RESPONSE PLAN (Continued)

Total Risk Rating	Risk Description	Risk Number	Risk response category	Risk Response
10	The concept design will create sparkles during mechanical scraping process	9	Mitigate	apply non-spark material on the edge of scraping tool
9	Operators find new process difficult to use, causes a failure of project design	3	Mitigate	Communicate with operators and improve design regarding to their requirements
9	Design is not practical to build or does not work for 420-gallon Baker-Perkins vertical mixer bowl	4	Mitigate	Look for improvement in order to come up with a realistic design
9	Residual propellant cannot be cleaned completely	10	Mitigate	Apply multiple cleaning cycles for the cleaning process
8	Design increases the processing time for cleaning	5	Mitigate	Look for improvements and do optimization on the existed design
6	Coating may come off after multiple use	12	Mitigate	Apply coating to the inner surface periodically

6	Coating is too thick for tolerance between blades and the inside surface	13	Mitigate	Change the size of blades to fit in the mixing bowl after coating
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TABLE XIII: RISK RESPONSE PLAN (Continued)

Total Risk Rating	Risk Description	Risk Number	Risk response category	Risk Response
6	Hard to control excessive wear on the outer diameter during vertical scraping motion	15	Mitigate	Design additional edge around outer diameter to complete vertical scraping motion
6	Team members become sick or are unable to work, which will cause a loss of team resources and impact the plan to complete the desired tasks	7	Mitigate	Reallocate team members tasks and reschedule the desired plan
6	Design fails to eliminate the need for the operator to climb inside the propellant mixer bowl	8	Mitigate	Improve existing design to minimize the operation process
4	Extendable Rod may cause buckling due to high scraping force	16	Mitigate	Increase the cross-sectional area of extendable rod to endure more internal force

4	Project exceeds the planned budget and causes dissatisfaction from client	2	Mitigate	Communicate with clients and ask if they can provide more budget for this project
3	Team member not abiding to team rules will cause a delay of desired tasks	6	Mitigate	Discuss team rules and responsibilities to make sure all the team members are agreed with team rules.

Appendix L: Installation Instructions

Installation instructions are included for specific assemblies that could confuse operators so that the operators may understand the design intent.

L.1 First Time Installation of Water System

1. The water system needs to have the main pipe and all the relevant T-joints and cross connections assembled before being placed inside of the main transmission shaft.
2. The holes on the main shaft will align with the threaded holes for the 6 different branch paths of the water system. The branches can then be threaded into the main piping. It is important to note that the branches should fit through the rubber grommets and not be touching the shaft to prevent risk of rubbing. Ensure that the connection is tight and sealed.
3. The water system will now be fixed to the transmission shaft and lifted out when the entire cleaning system is removed via the crane

L.2 First Time Installation of Mechanical System

In order to assemble the mechanical system following steps are to be followed in sequential order:

1. Install all the sub components as shown in SUB_ASSEMBLY 2 (LID AND CLAMP ASSEMBLY DWG) onto the LID PART_06 as shown in Appendix M - Engineering Drawings.

2. Install the water pressurized system in the SUB ASSEMBLY 5 (SIDE WALL SCRAPER ASSEMBLY DRAWING) by following the steps from L.1 First Time Installation of Water System as shown above.

NOTE: The SUB ASSEMBLY 5 is welded and weighs approximately 65 lbs ensure safe work procedure when assembling the water pressurized system
3. Lift the entire assembly with a combination of water pressurized system installed in step 2 in conjunction with SUB ASSEMBLY 5 into the mixing bowl.
4. Lift the SUB_ASSEMBLY 2 (LID AND CLAMP ASSEMBLY DWG) and align it with the transmission shaft assembled in step 3. There clearance hole of 3.125 inch provide an ease of alignment to the shaft diameter of 3 inch. Before proceeding to step 5 ensure the lid is aligned with the holes of the mixing bowl and clamp the lid using push down toggle clamp.
5. Add the retaining ring on the shaft and than assemble the bearing ensure the set screw are tighten until the allen key starts twisting.
6. Assemble all the other components as shown in SUB ASSEMBLY 1_MOTOR ASSEMBLY DRAWING.

NOTE: After the first installation It is not necessary to remove all the components unless there is any damage. Once the cleaning is done all the assembly can be lifted with the help of three rotating eye bolt located on the lid without removing any sub assemblies.

Moreover, the retaining ring will support the load of the whole assembly weighing approximately 305 lbs as the retaining ring provides a thrust load capacity of 33,300 lbs. It is recommended to check the shaft for any damages on the location of the retaining ring after lifting the whole assembly. If there is any damage the shaft diameter can be reduced to add a shoulder instead.

L.3 External Connections

Upon the start of the cleaning process the cleaning system will have several external hookups. The list of connections that need to be connected before and after the cleaning cycle are as follows:

1. The pressurized water system will have an external connection requiring hookup to a pressure washer.

Note: If the pressure washer can incorporate a soap solution with the water, then this is recommended

2. The hydraulic motor will have to be connected to the external hydraulic system for the power input.

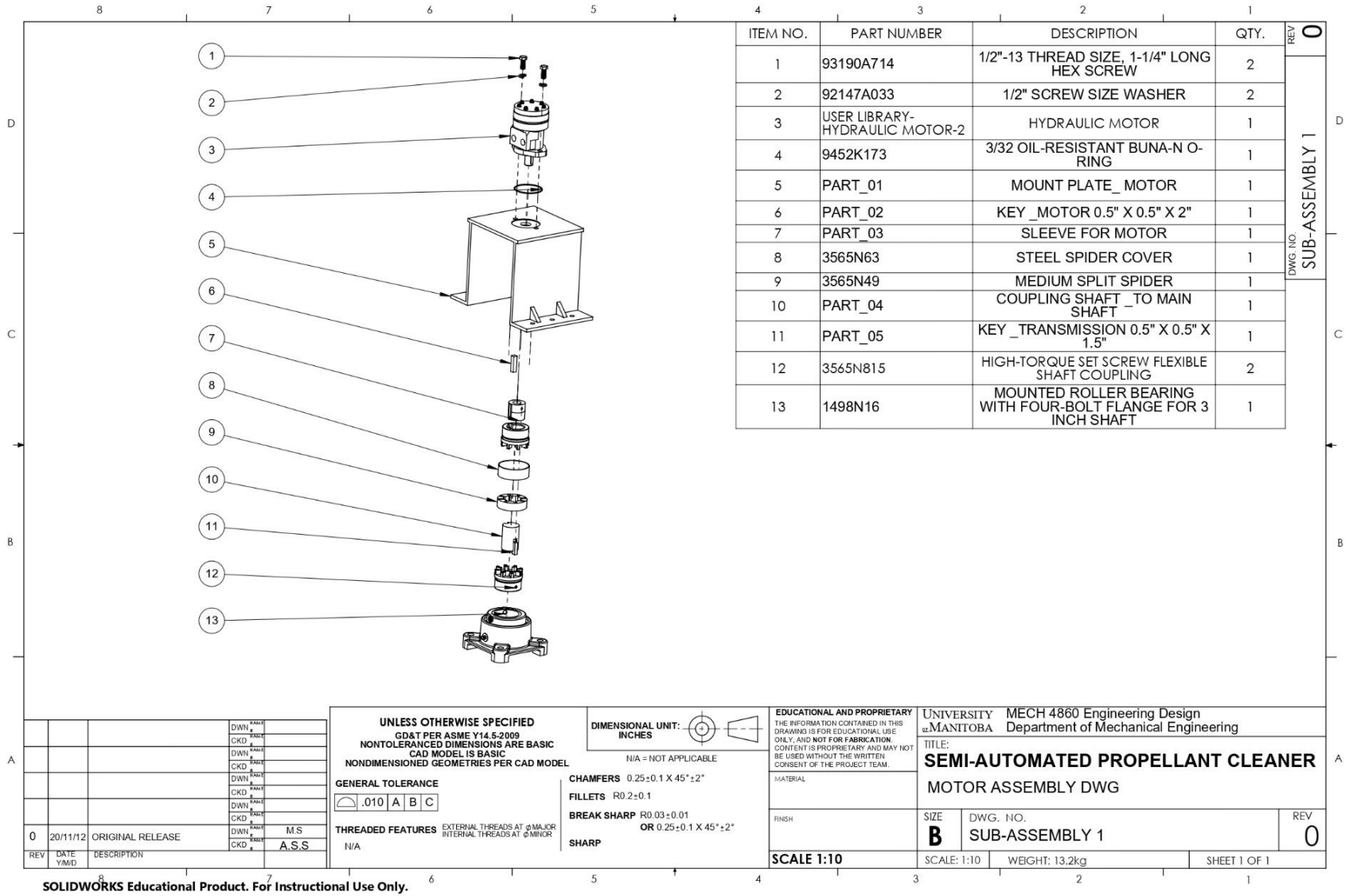
L.4 Cleaning Procedure

The cleaning procedure consists of number of different steps that needs to be followed in sequential order as mentioned below:

1. Insert the pressurized water system on the subassembly (first time installation).
2. The assembly will be done in house while all the subcomponents are assembled such as blades on shaft, clamps, mounting plate on the lid (first time installation).
3. Insert water pipe inside the hollow shaft and connect pressurized water system.
4. Connect shaft to the lid by installing bearing, couplers, hydraulic motor and mounting plate.
5. Lift lid by hooking the three rotating eyebolts.
6. Insert assembly into mixer bowl, fix dowel pin and clamp the lid using toggle clamps.
7. Assemble hydraulic power system
8. Connect pressurized water system with swivel joint through funnel.
9. Cleaning process Phase I (pressurized water system open).
10. Cleaning process Phase II (pressurized water system closed).
11. Take out and clean the assembly, Store the assembly indoors in a clean, dry, noncorrosive atmosphere.

Appendix M - Engineering Drawings

This section provides all the engineering technical drawings and Bill of Material (BOM) for each sub assemblies for the parts designed by the team. All the other part drawings can be found on the McMaster Carr with their detail part number mentioned in the BOM.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	93190A714	1/2"-13 THREAD SIZE, 1-1/4" LONG HEX SCREW	2
2	92147A033	1/2" SCREW SIZE WASHER	2
3	USER LIBRARY-HYDRAULIC MOTOR-2	HYDRAULIC MOTOR	1
4	9452K173	3/32 OIL-RESISTANT BUNA-N O-RING	1
5	PART_01	MOUNT PLATE_MOTOR	1
6	PART_02	KEY_MOTOR 0.5" X 0.5" X 2"	1
7	PART_03	SLEEVE FOR MOTOR	1
8	3565N63	STEEL SPIDER COVER	1
9	3565N49	MEDIUM SPLIT SPIDER	1
10	PART_04	COUPLING SHAFT TO MAIN SHAFT	1
11	PART_05	KEY_TRANSMISSION 0.5" X 0.5" X 1.5"	1
12	3565N815	HIGH-TORQUE SET SCREW FLEXIBLE SHAFT COUPLING	2
13	1498N16	MOUNTED ROLLER BEARING WITH FOUR-BOLT FLANGE FOR 3 INCH SHAFT	1

REV	0
DWG NO.	SUB-ASSEMBLY 1
SCALE	1:10
WEIGHT	13.2kg
SHEET	1 OF 1

REV	DATE	DESCRIPTION	BY	CHKD
0	20/11/12	ORIGINAL RELEASE	M.S	A.S.S

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B C

THREADED FEATURES
 N/A

EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR

DIMENSIONAL UNIT:
 INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
 FILLETS R0.2±0.1
 BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
 SHARP

EDUCATIONAL AND PROPRIETARY
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS FOR EDUCATIONAL USE
 ONLY, AND NOT FOR FABRICATION.
 CONTENT IS PROPRIETARY AND MAY NOT
 BE USED WITHOUT THE WRITTEN
 CONSENT OF THE PROJECT TEAM.

MATERIAL

FINISH

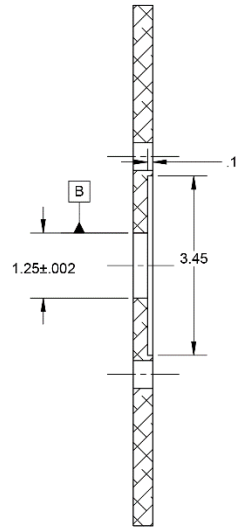
UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
 MOTOR ASSEMBLY DWG

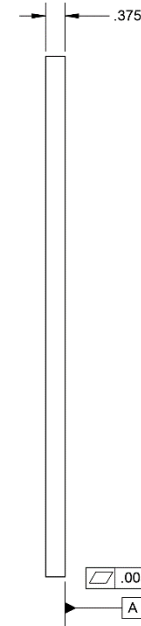
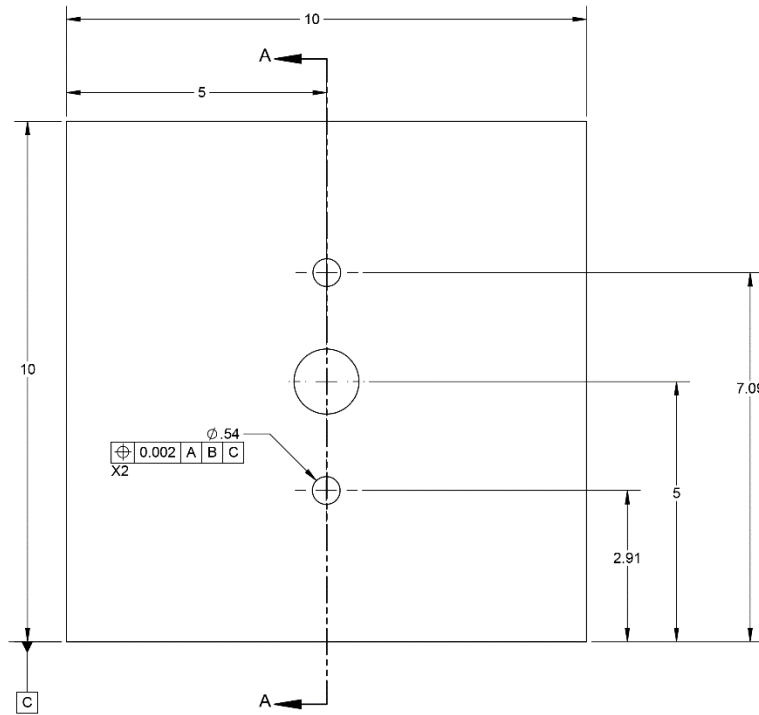
SIZE **B** DWG. NO. SUB-ASSEMBLY 1 REV **0**

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



SECTION A-A



REV 0
DWG. NO. PART_01_01

			DWN	
			CKD	
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			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
REV	DATE	DESCRIPTION	CKD	
	Y/M/D			

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25 ± 0.1 X 45° ± 2°

FILLETS R0.2 ± 0.1

BREAK SHARP R0.03 ± 0.01
 OR 0.25 ± 0.1 X 45° ± 2°

SHARP

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MATERIAL
 STAINLESS STEEL - 316

FINISH
 14

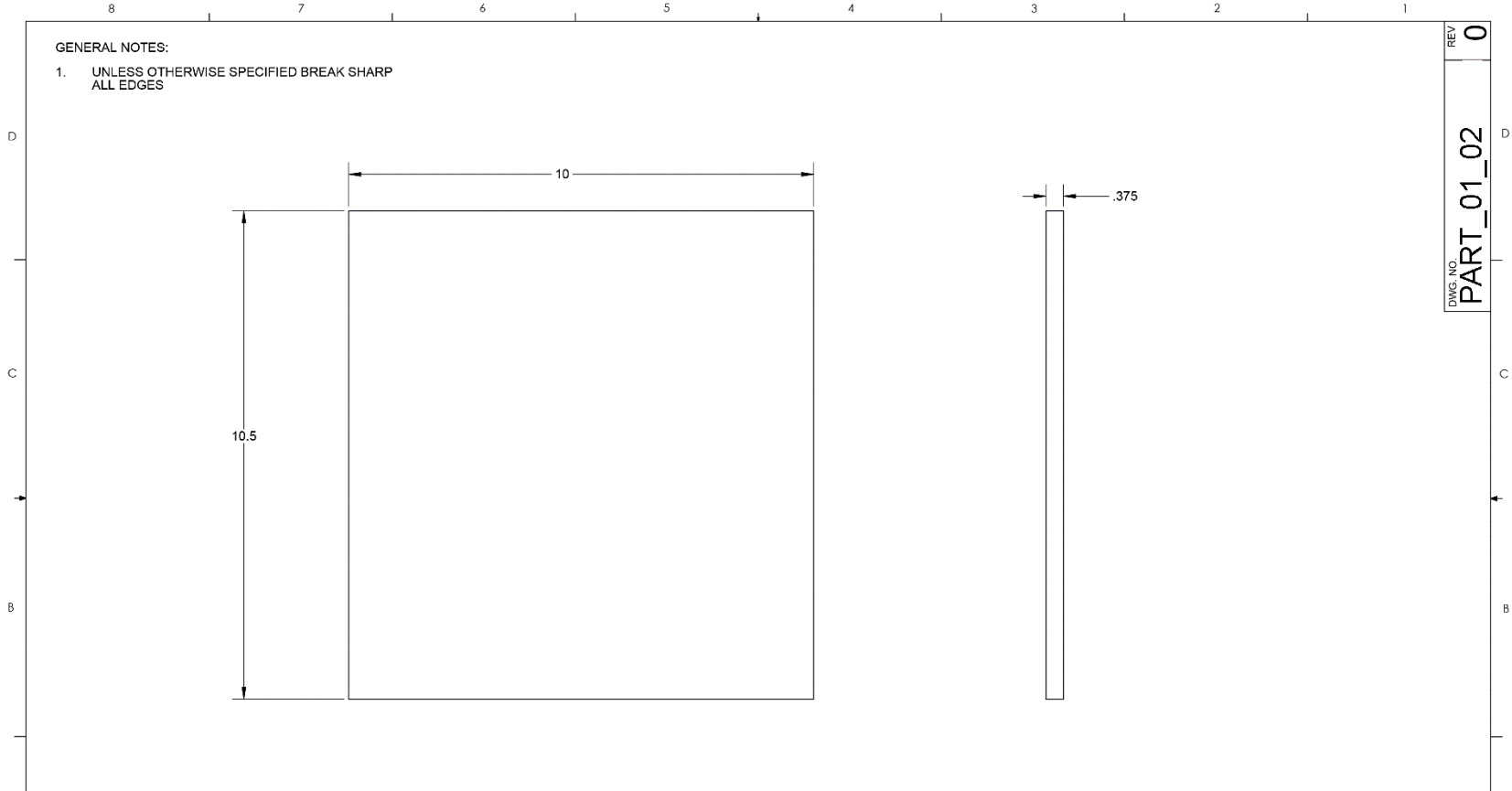
DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
UPPER MOUNTED PLATE

SIZE B
DWG. NO. PART_01_01
REV 0

SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 4



GENERAL NOTES:
 1. UNLESS OTHERWISE SPECIFIED BREAK SHARP
 ALL EDGES

REV 0
 DWG. NO. PART_01_02

			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
REV	DATE	DESCRIPTION	BY	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

GENERAL TOLERANCE
 .010 | A | B | C

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01 OR 0.25±0.1 X 45°±2°
SHARP

THREADED FEATURES EXTERNAL THREADS AT ØMAJOR
 INTERNAL THREADS AT ØMINOR
 N/A

EDUCATIONAL AND PROPRIETARY
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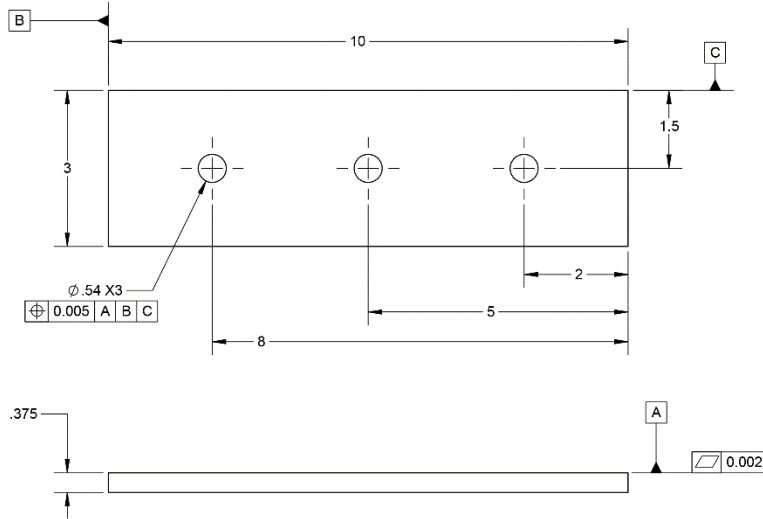
MATERIAL
 STAINLESS STEEL - 316

FINISH
 1/6

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering	
TITLE: SEMI-AUTOMATED PROPELLANT CLEANER SIDE MOUNTING PLATE	
SIZE B	DWG. NO. PART_01_02
DO NOT SCALE DRAWING	REV 0
SCALE: 1:2	WEIGHT: N/A
SHEET 4 OF 4	

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP
ALL EDGES



REV 0
DWG. NO. PART_01_03

			DWN ⁰⁰⁰¹
			CKD ⁰⁰⁰¹
			DWN ⁰⁰⁰¹
			CKD ⁰⁰⁰¹
			DWN ⁰⁰⁰¹
			CKD ⁰⁰⁰¹
			DWN ⁰⁰⁰¹
			CKD ⁰⁰⁰¹
0	20/11/12	ORIGINAL RELEASE	A.S.S
REV	DATE	DESCRIPTION	
	Y/M/D		

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
0.10 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
INTERNAL THREADS AT Ø MINOR
N/A

DIMENSIONAL UNIT:
INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
STAINLESS STEEL - 316

FINISH
1.6

DO NOT SCALE DRAWING

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Department of Mechanical Engineering

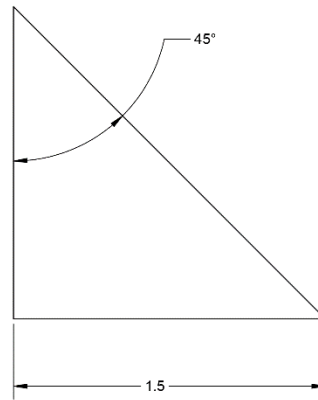
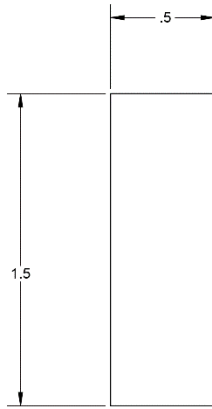
TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
BOTTOM MOUNTING PLATE

SIZE DWG. NO. REV
B PART_01_03 0

SCALE: 1:2 WEIGHT: N/A SHEET 3 OF 4

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



REV 0
DWG. NO. PART_01_04

			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
REV	DATE	DESCRIPTION	DWN	
	Y/M/D		CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 [A] [B] [C]

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT:
 INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 STAINLESS STEEL - 316

FINISH
 16 ✓

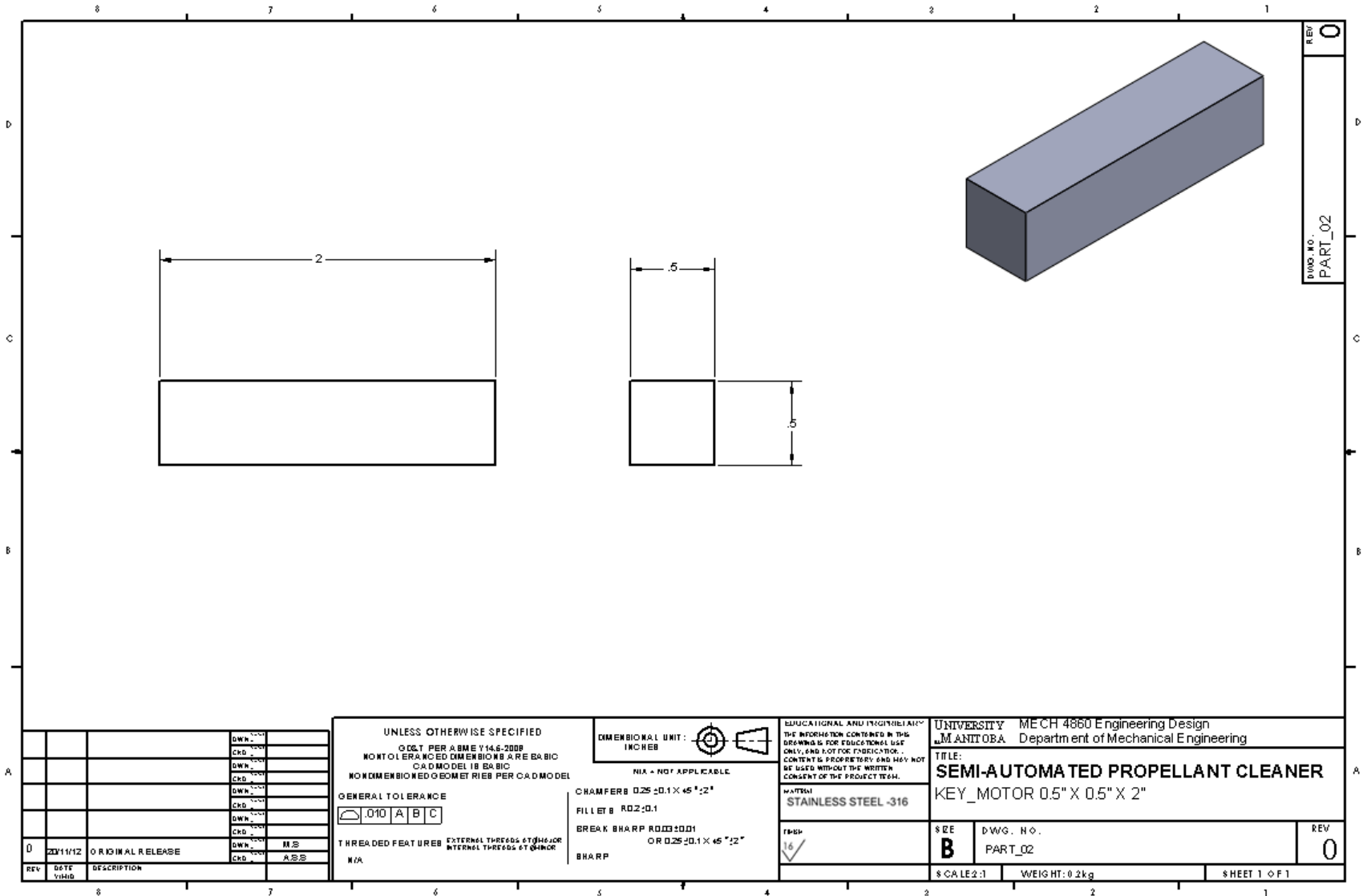
DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
GUSSET

SIZE **B** **DWG. NO.** PART_01_04 **REV** 0

SCALE 1:1 WEIGHT: N/A SHEET 2 OF 4



REV 0
PART_02

REV	DATE	DESCRIPTION	DWN	CHK
0	2011/12	ORIGINAL RELEASE	M.S	A.S.S

UNLESS OTHERWISE SPECIFIED
 Q DLT PER ASME Y14.5-2009
 NO TOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NO DIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B C

THREADED FEATURES
 N/A

DIMENSIONAL UNIT:
 INCHES

N/A - NOT APPLICABLE

CHAMFERS .025 ± .01 X 45 ° ± .2°
 FILLET R R02 ± .01
 BREAK SHARP R00 ± .001
 OR 0.25 ± .01 X 45 ° ± .2°
 SHARP

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 CONSENT OF THE PROJECT TEAM.

MATERIAL
 STAINLESS STEEL -316

FINISH
 16 ✓

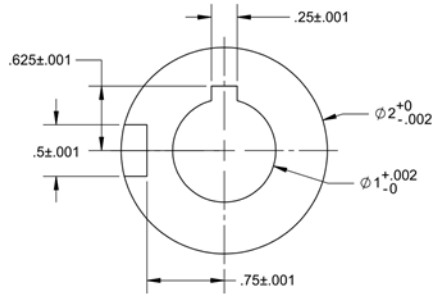
UNIVERSITY OF MANITOBA
 MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
 KEY_MOTOR 0.5" X 0.5" X 2"

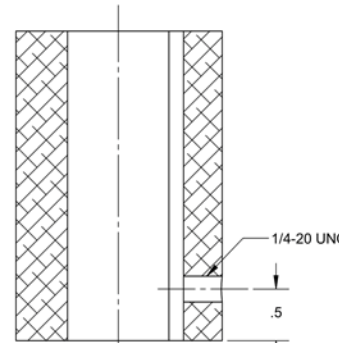
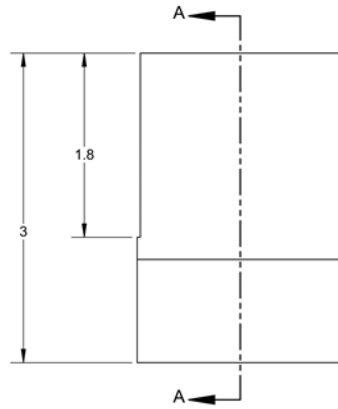
SCALE: 2:1
 WEIGHT: 0.2kg
 SHEET 1 OF 1

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



ISO VIEW
SCALE 1:1



SECTION A-A
SCALE 1 : 1

REV	DATE	DESCRIPTION	DWN	CKD
0	20/11/12	ORIGINAL RELEASE	A.S.S	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE

.010	A	B	C
------	---	---	---

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
INTERNAL THREADS AT Ø MINOR
N/A

DIMENSIONAL UNIT:
INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45° ±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
OR 0.25±0.1 X 45° ±2°
SHARP

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MATERIAL
STAINLESS STEEL -316

FINISH
16

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
Department of Mechanical Engineering

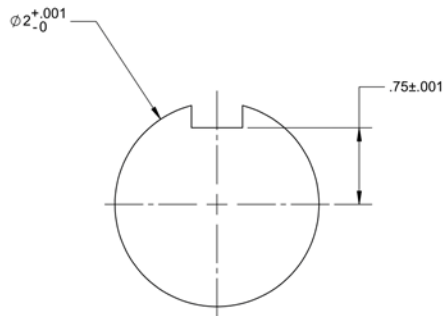
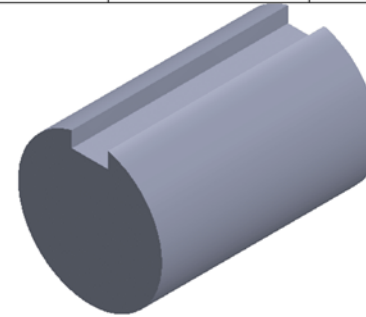
TITLE:
**SEMI-AUTOMATED PROPELLANT CLEANER
SLEEVE FOR HYDRAULIC MOTOR**

SIZE **B** DWG. NO. **PART_03** REV **0**

DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 1

GENERAL NOTES:

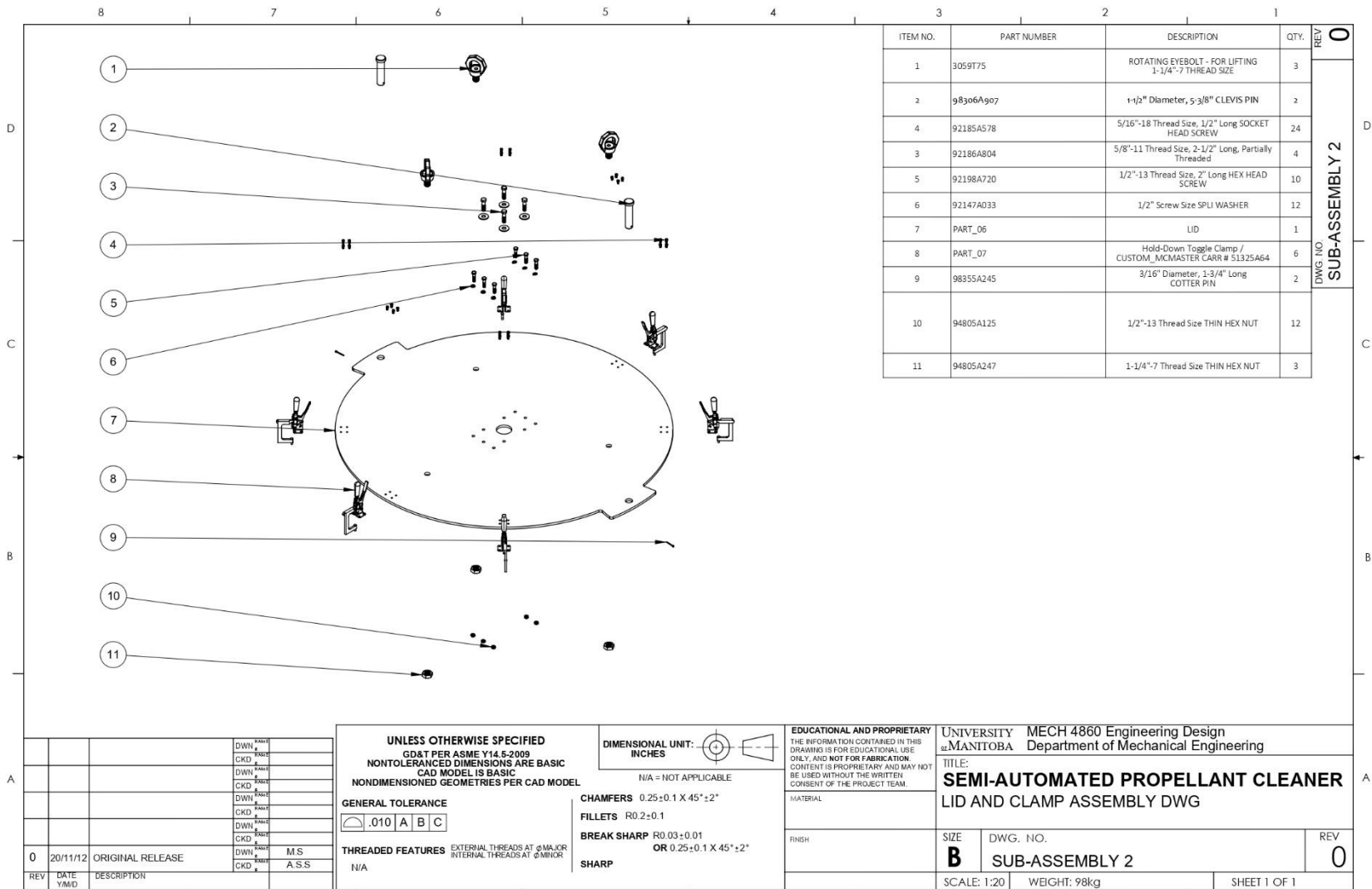
- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



REV 0
DWG NO PART_04

REV	DATE Y/M/D	DESCRIPTION	DWN	CKD	A.S.S
0	20/11/12	ORIGINAL RELEASE	DWN	CKD	A.S.S

<p>UNLESS OTHERWISE SPECIFIED GD&T PER ASME Y14.5-2009 NONTOLERANCED DIMENSIONS ARE BASIC CAD MODEL IS BASIC NONDIMENSIONED GEOMETRIES PER CAD MODEL</p>		<p>DIMENSIONAL UNIT: INCHES</p> <p>N/A = NOT APPLICABLE</p>	<p>EDUCATIONAL AND PROPRIETARY THE INFORMATION CONTAINED IN THIS DRAWING IS FOR EDUCATIONAL USE ONLY, AND NOT FOR FABRICATION. CONTENT IS PROPRIETARY AND MAY NOT BE USED WITHOUT THE WRITTEN CONSENT OF THE PROJECT TEAM.</p>	<p>UNIVERSITY OF MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering</p>
<p>GENERAL TOLERANCE</p> <p>$\frac{\varnothing}{16}$.010 A B C</p>	<p>CHAMFERS 0.25 ± 0.1 X 45° ± 2°</p> <p>FILLETS R0.2 ± 0.1</p> <p>BREAK SHARP R0.03 ± 0.01 OR 0.25 ± 0.1 X 45° ± 2°</p> <p>SHARP</p>	<p>MATERIAL STAINLESS STEEL -316</p>	<p>TITLE: SEMI-AUTOMATED PROPELLANT CLEANER COUPLING FOR TRANSMISSION SHAFT</p>	
<p>THREADED FEATURES EXTERNAL THREADS AT <math>\varnothing</math> MAJOR INTERNAL THREADS AT <math>\varnothing</math> MINOR</p> <p>N/A</p>	<p>FINISH 16 ✓</p>	<p>SCALE: 1:2</p>	<p>SIZE B</p> <p>DWG. NO. PART_04</p> <p>WEIGHT: N/A</p>	<p>REV 0</p> <p>SHEET 1 OF 1</p>
<p>DO NOT SCALE DRAWING</p>				



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	3059T75	ROTATING EYEBOLT - FOR LIFTING 1-1/4"-7 THREAD SIZE	3
2	983o6A9o7	1+1/2" Diameter, 5-3/8" CLEVIS PIN	2
4	92185A578	5/16"-18 Thread Size, 1/2" Long SOCKET HEAD SCREW	24
3	92186A804	5/8"-11 Thread Size, 2-1/2" Long, Partially Threaded	4
5	92198A720	1/2"-13 Thread Size, 2" Long HEX HEAD SCREW	10
6	92147A033	1/2" Screw Size SPLI WASHER	12
7	PART_06	LID	1
8	PART_07	Hold-Down Toggle Clamp / CUSTOM_MCMMASTER CARR # 51325A64	6
9	98355A245	3/16" Diameter, 1-3/4" Long COTTER PIN	2
10	94805A125	1/2"-13 Thread Size THIN HEX NUT	12
11	94805A247	1-1/4"-7 Thread Size THIN HEX NUT	3

REV 0
DWG. NO. SUB-ASSEMBLY 2

REV	DATE Y/M/D	DESCRIPTION	DWGN #	EXC #	DATE Y/M/D	DESCRIPTION	DWGN #	EXC #
0	20/11/12	ORIGINAL RELEASE						

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT:
 INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETs R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL

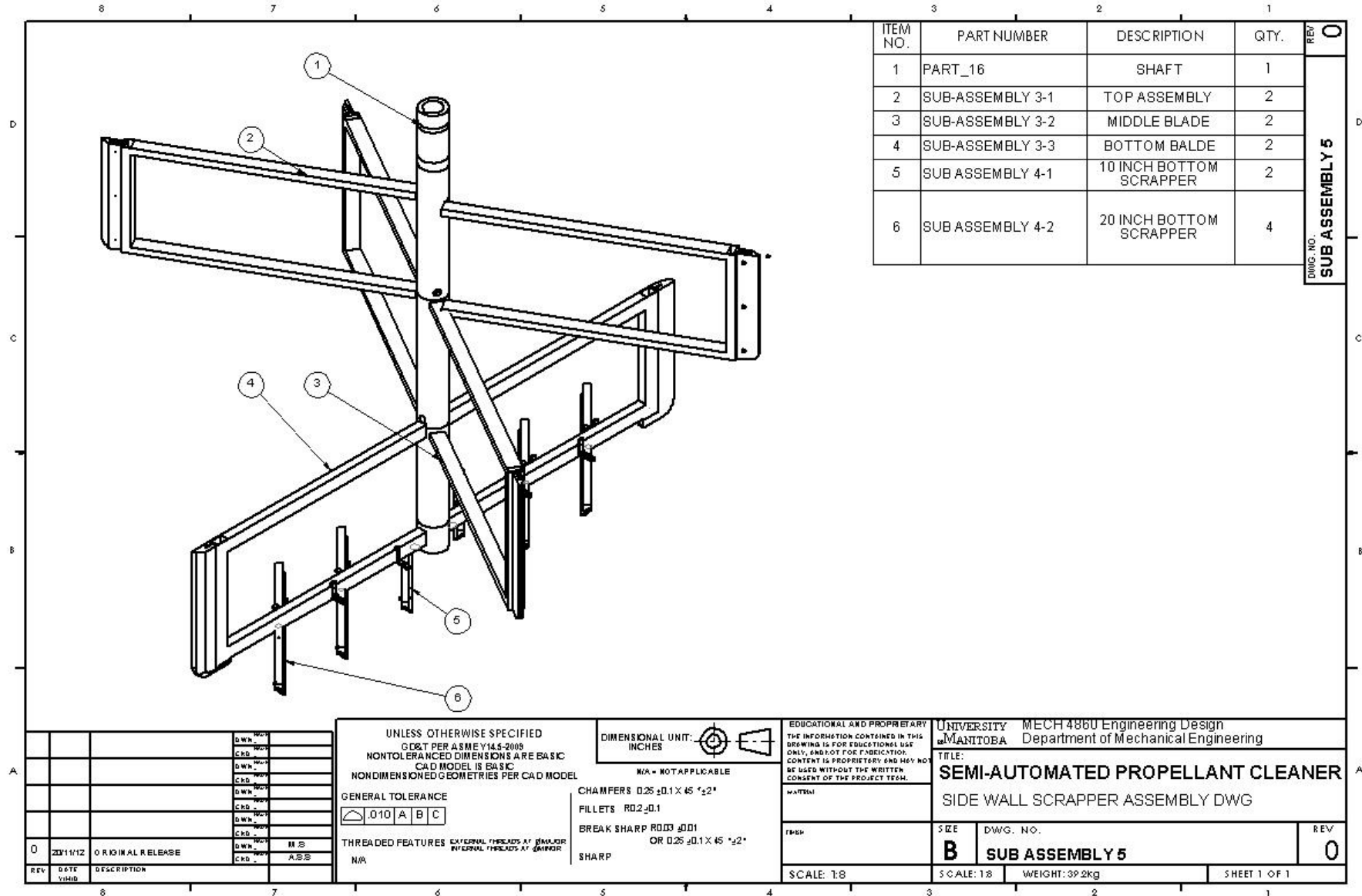
FINISH

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
**SEMI-AUTOMATED PROPELLANT CLEANER
 LID AND CLAMP ASSEMBLY DWG**

SCALE: 1:20 **WEIGHT:** 98kg **SHEET** 1 OF 1

SIZE B **DWG. NO.** SUB-ASSEMBLY 2 **REV** 0



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.	REV
1	PART_16	SHAFT	1	0
2	SUB-ASSEMBLY 3-1	TOP ASSEMBLY	2	
3	SUB-ASSEMBLY 3-2	MIDDLE BLADE	2	
4	SUB-ASSEMBLY 3-3	BOTTOM BLADE	2	
5	SUB ASSEMBLY 4-1	10 INCH BOTTOM SCRAPER	2	
6	SUB ASSEMBLY 4-2	20 INCH BOTTOM SCRAPER	4	

DWG. NO. **SUB ASSEMBLY 5**

REV	DATE	DESCRIPTION	DWN	CHK	APP
0	20/11/12	ORIGINAL RELEASE			

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 ± 0.10 A B C

THREADED FEATURES EXTERNAL THREADS AT ØHOLE
 INTERNAL THREADS AT ØHOLE
 NA

DIMENSIONAL UNIT:
 INCHES

NA = NOT APPLICABLE

CHAMFERS 0.25 ±0.1 X 45 ° ±2°
 FILLETS R0.2 ±0.1
 BREAK SHARP R0.03 ±0.01
 OR 0.25 ±0.1 X 45 ° ±2°
 SHARP

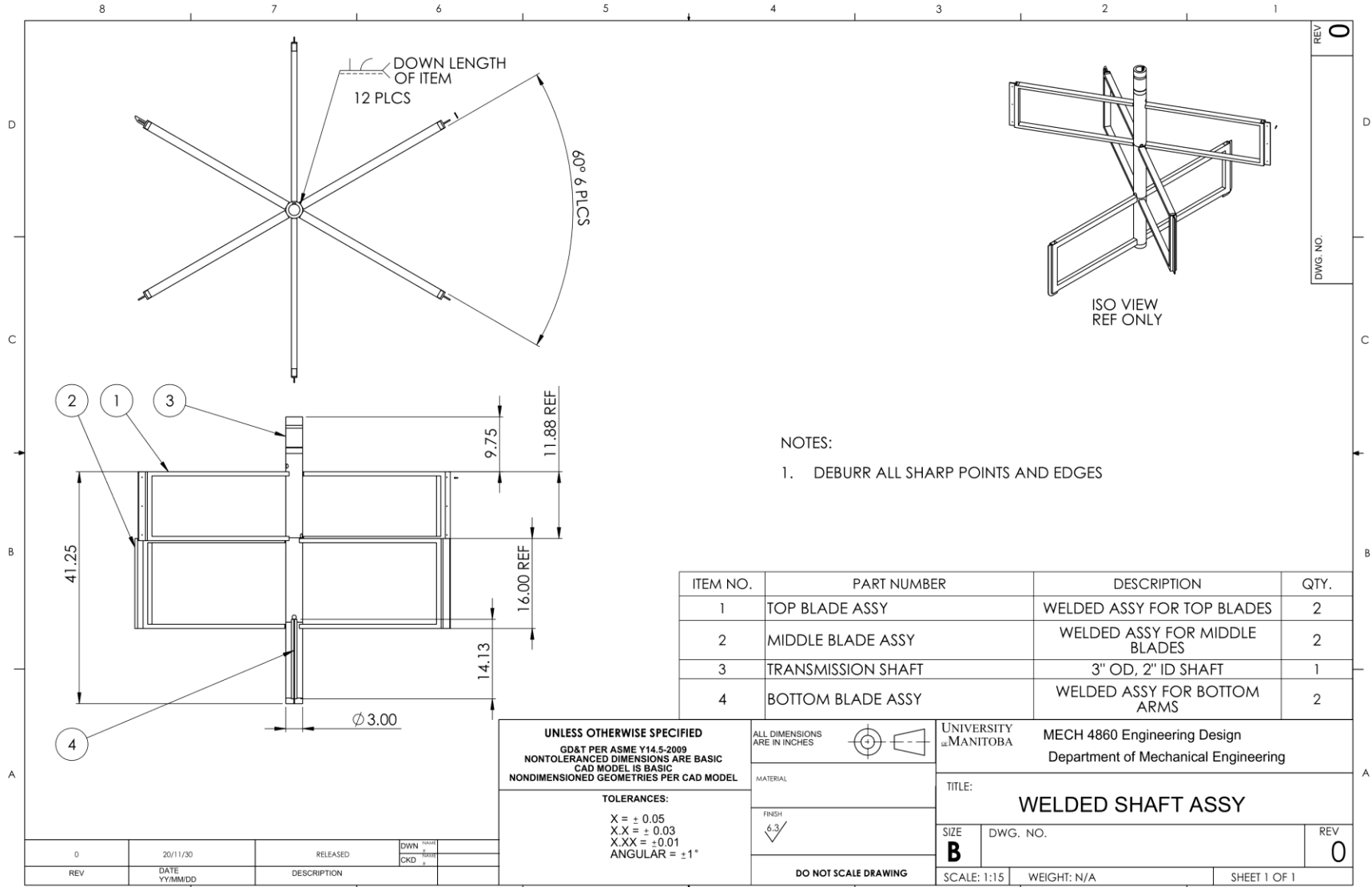
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UNIVERSITY OF MANITOBA
 MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
 SIDE WALL SCRAPER ASSEMBLY DWG

SCALE: 1:8

SIZE	DWG. NO.	REV
B	SUB ASSEMBLY 5	0
SCALE: 1:8		WEIGHT: 39.2kg
SHEET 1 OF 1		



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NOTES:
1. DEBURR ALL SHARP POINTS AND EDGES

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	TOP BLADE ASSY	WELDED ASSY FOR TOP BLADES	2
2	MIDDLE BLADE ASSY	WELDED ASSY FOR MIDDLE BLADES	2
3	TRANSMISSION SHAFT	3" OD, 2" ID SHAFT	1
4	BOTTOM BLADE ASSY	WELDED ASSY FOR BOTTOM ARMS	2

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

TOLERANCES:
 X = ± 0.05
 X.X = ± 0.03
 X.XX = ± 0.01
 ANGULAR = ± 1°

ALL DIMENSIONS ARE IN INCHES

MATERIAL

FINISH
 6.3

DO NOT SCALE DRAWING

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 MECH 4860 Engineering Design
 Department of Mechanical Engineering

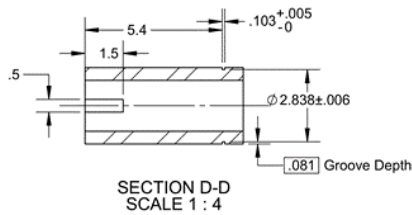
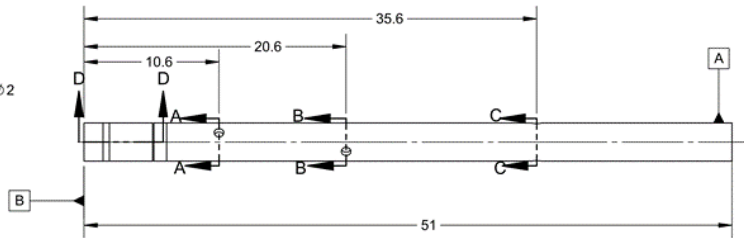
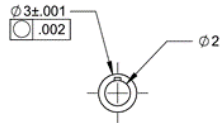
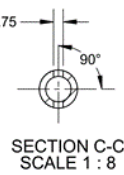
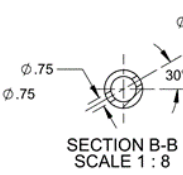
TITLE:
WELDED SHAFT ASSY

SIZE **B** DWG. NO. REV **0**

SCALE: 1:15 WEIGHT: N/A SHEET 1 OF 1

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
			CKD	
REV	DATE	DESCRIPTION		

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
0.1 A B C

THREADED FEATURES EXTERNAL THREADS AT ϕ MAJOR
INTERNAL THREADS AT ϕ MINOR
N/A

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

CHAMFERS $0.25 \pm 0.1 \times 45^\circ \pm 2^\circ$
FILLETS $R0.2 \pm 0.1$
BREAK SHARP $R0.03 \pm 0.01$
OR $0.25 \pm 0.1 \times 45^\circ \pm 2^\circ$
SHARP

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MATERIAL
STAINLESS STEEL -316

FINISH
3.2

DO NOT SCALE DRAWING

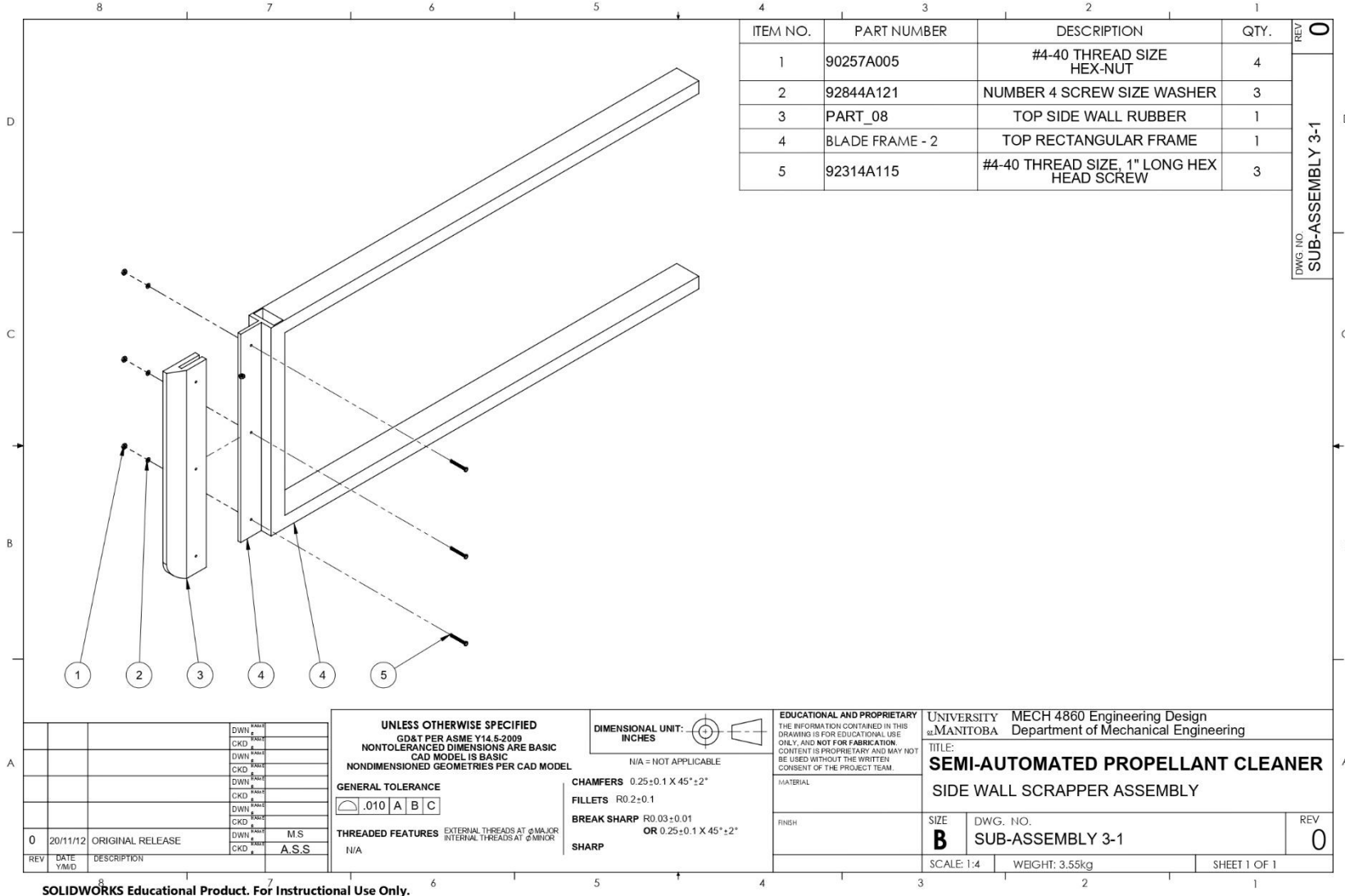
UNIVERSITY MECH 4860 Engineering Design
MANITOBA Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER TRANSMISSION SHAFT

SIZE B **DWG. NO.** PART_16 **REV** 0

SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 1

REV 0
DWG. NO. Transmission Shaft



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	90257A005	#4-40 THREAD SIZE HEX-NUT	4
2	92844A121	NUMBER 4 SCREW SIZE WASHER	3
3	PART_08	TOP SIDE WALL RUBBER	1
4	BLADE FRAME - 2	TOP RECTANGULAR FRAME	1
5	92314A115	#4-40 THREAD SIZE, 1" LONG HEX HEAD SCREW	3

REV	0
DWG. NO.	SUB-ASSEMBLY 3-1

REV	DATE	DESCRIPTION	DWN #	CDK #
0	20/11/12	ORIGINAL RELEASE	M.S	A.S.S

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES
 N/A

EXTERNAL THREADS AT Ø MAJOR
INTERNAL THREADS AT Ø MINOR

DIMENSIONAL UNIT:
 INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45° ±2°
FILLET R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45° ±2°
SHARP

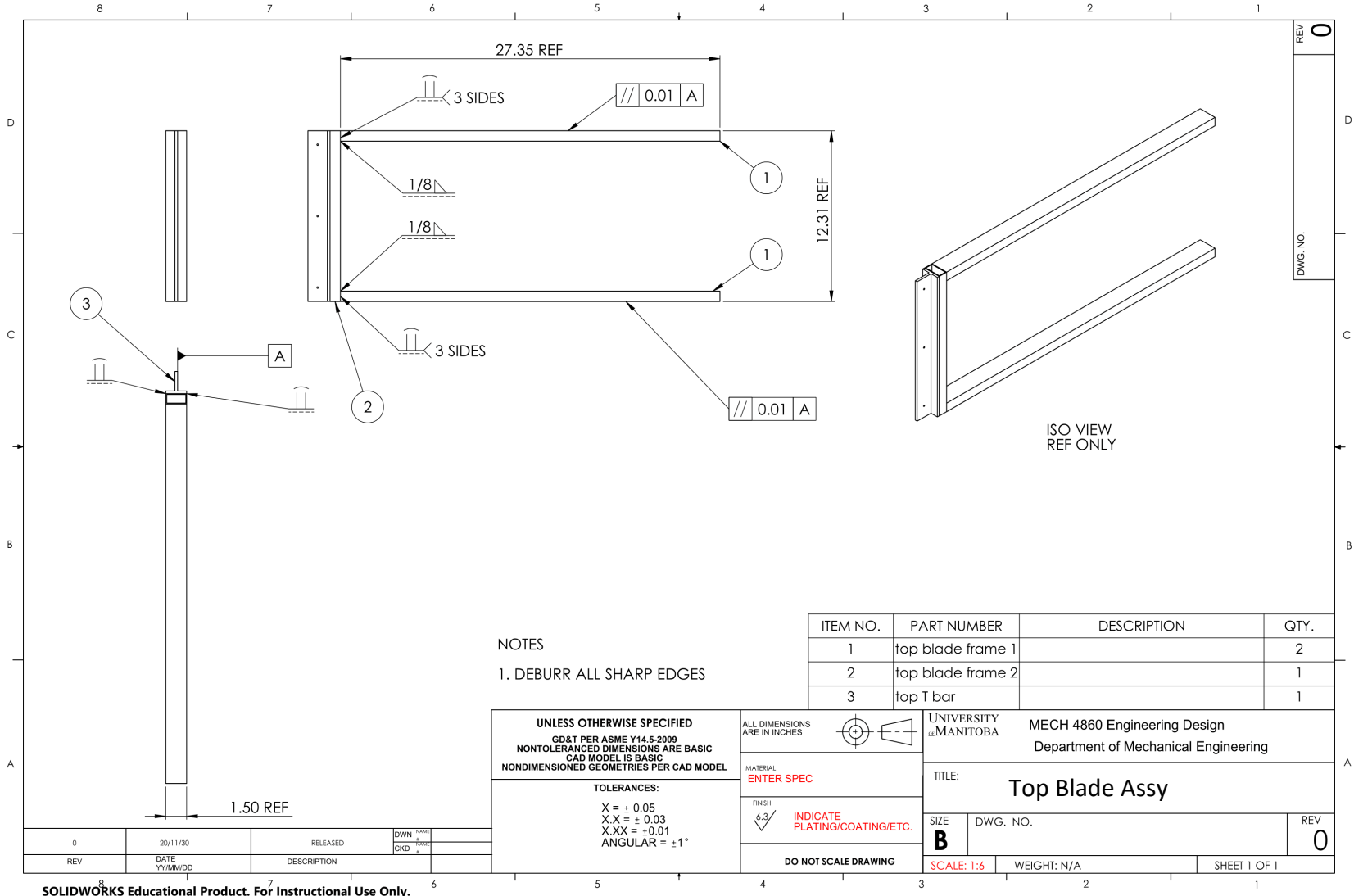
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 MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
SIDE WALL SCRAPER ASSEMBLY

SIZE B
DWG. NO. SUB-ASSEMBLY 3-1
REV 0

SCALE: 1:4 WEIGHT: 3.55kg SHEET 1 OF 1



NOTES
1. DEBURR ALL SHARP EDGES

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	top blade frame 1		2
2	top blade frame 2		1
3	top T bar		1

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

TOLERANCES:
 X = ± 0.05
 X.X = ± 0.03
 X.XX = ± 0.01
 ANGULAR = ± 1°

ALL DIMENSIONS ARE IN INCHES

MATERIAL: ENTER SPEC

FINISH: 6.3 INDIcate PLATING/COATING/ETC.

DO NOT SCALE DRAWING

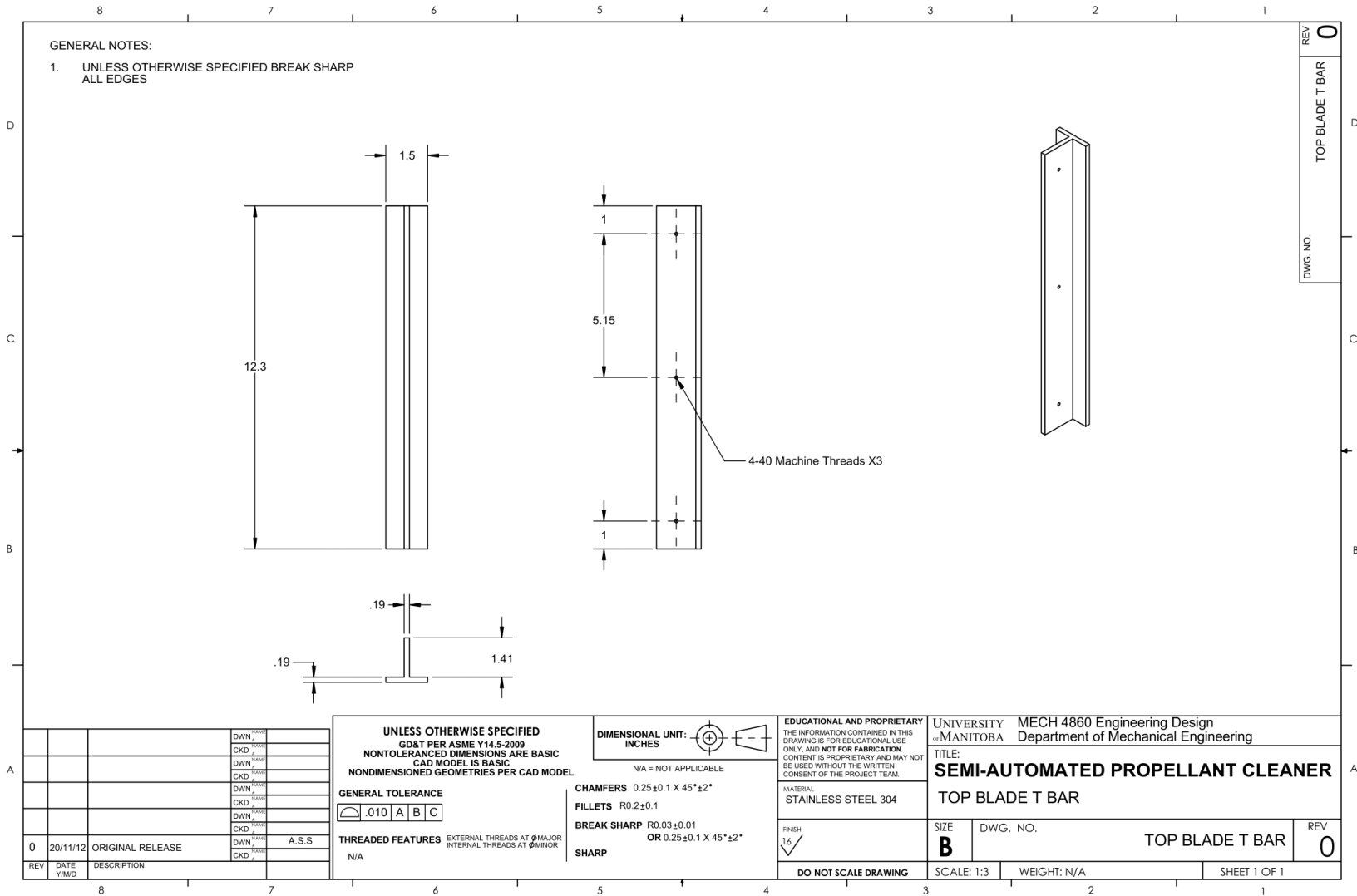
UNIVERSITY OF MANITOBA
 MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE: **Top Blade Assy**

SIZE: **B** DWG. NO. REV: **0**

SCALE: 1:6 WEIGHT: N/A SHEET 1 OF 1

REV	DATE	DESCRIPTION	DWN CKD	DATE	DESCRIPTION
0	20/11/30	RELEASED			



			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
REV	DATE	DESCRIPTION	CKD	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT:
 INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 STAINLESS STEEL 304

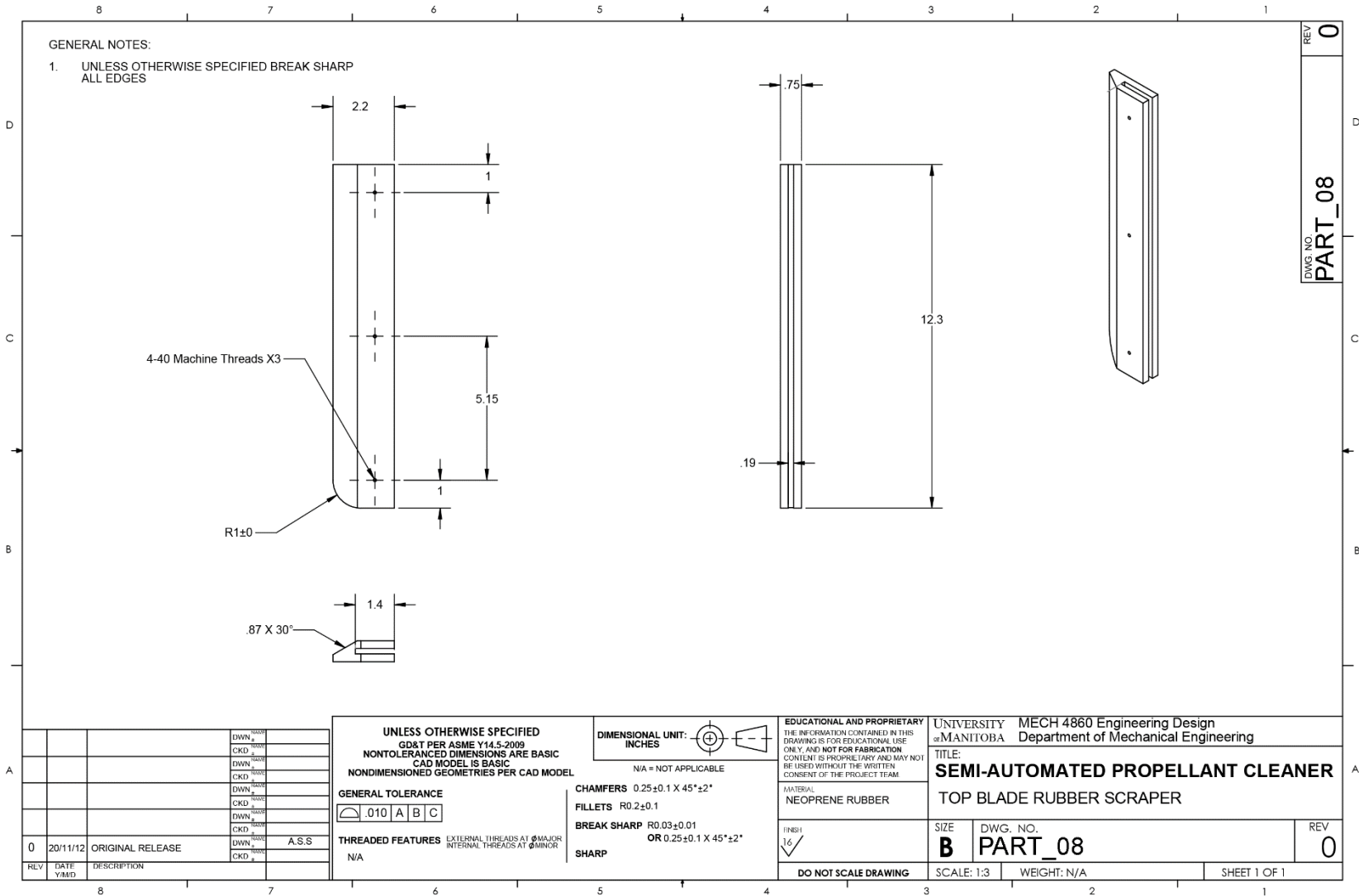
FINISH
 1/6

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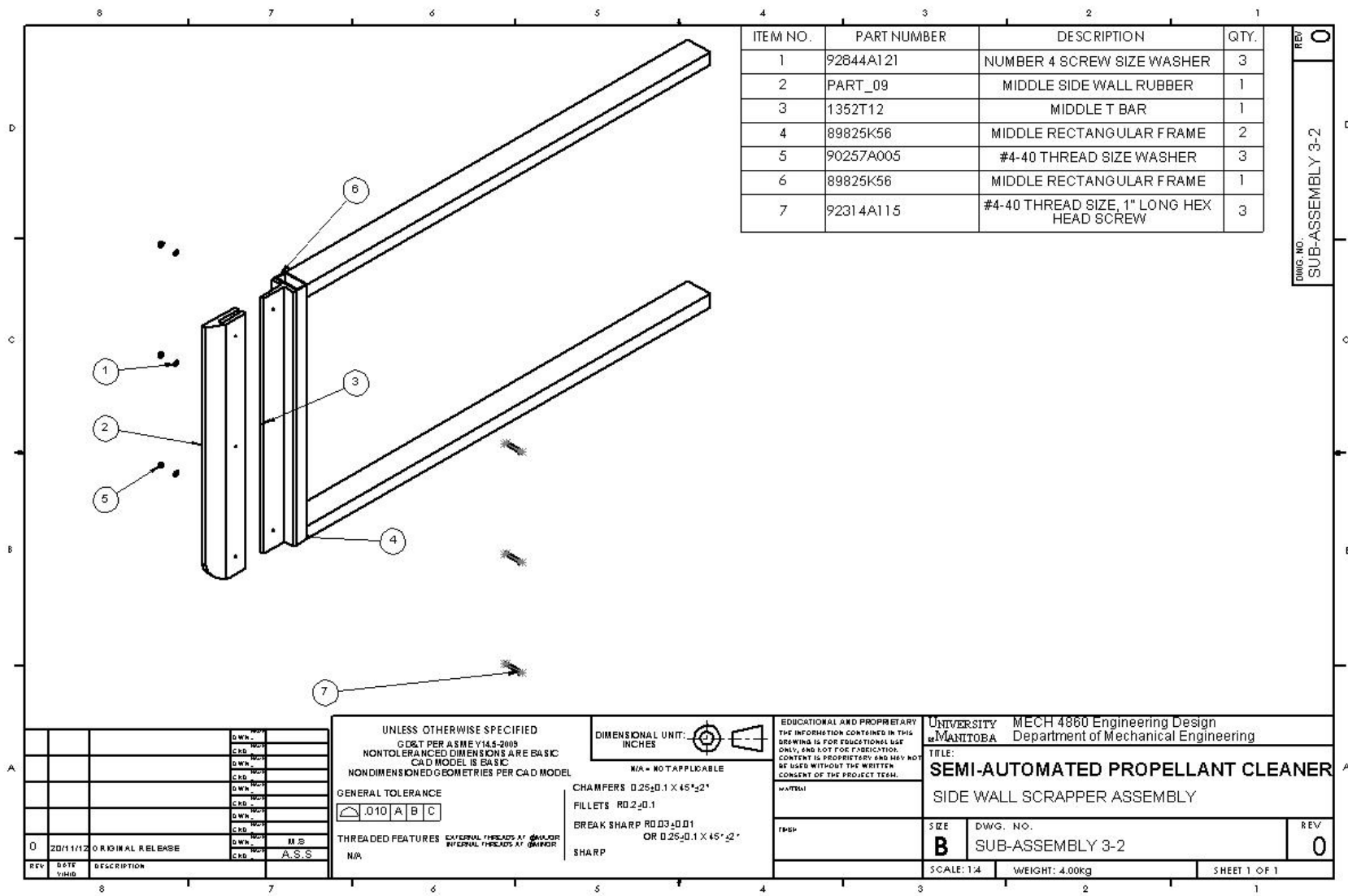
TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
 TOP BLADE T BAR

SIZE B
DWG. NO. TOP BLADE T BAR
REV 0

DO NOT SCALE DRAWING
 SCALE: 1:3 WEIGHT: N/A SHEET 1 OF 1



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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	92844A1 21	NUMBER 4 SCREW SIZE WASHER	3
2	PART_09	MIDDLE SIDE WALL RUBBER	1
3	1352T12	MIDDLE T BAR	1
4	89825K56	MIDDLE RECTANGULAR FRAME	2
5	90257A005	#4-40 THREAD SIZE WASHER	3
6	89825K56	MIDDLE RECTANGULAR FRAME	1
7	92314A115	#4-40 THREAD SIZE, 1" LONG HEX HEAD SCREW	3

DWG. NO.	0
REV	
SUB-ASSEMBLY 3-2	

REV	DATE	DESCRIPTION	DWN.	CHKD.
0	2011/1/2	ORIGINAL RELEASE	M.S.	A.S.S.

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B C

THREADED FEATURES
 NA

CHAMFERS $0.25 \pm 0.1 \times 45^\circ \pm 2^\circ$
 FILLETS $R0.2 \pm 0.1$
 BREAK SHARP $R0.03 \pm 0.01$
 OR $0.25 \pm 0.1 \times 45^\circ \pm 2^\circ$
 SHARP

DIMENSIONAL UNIT:
 INCHES

N/A - NOT APPLICABLE

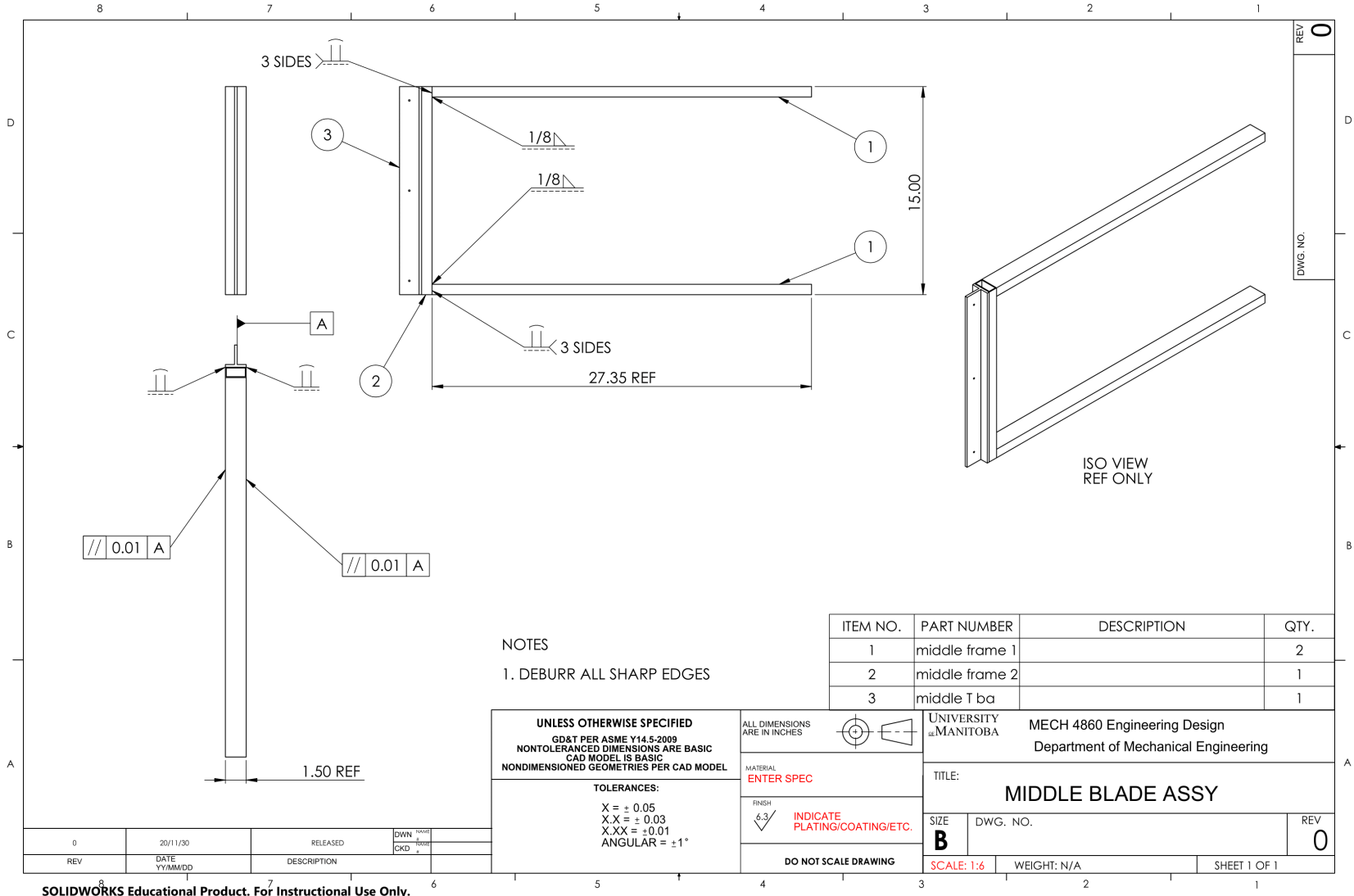
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UNIVERSITY OF MANITOBA
 MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
 SIDE WALL SCRAPER ASSEMBLY

SCALE: 1:4
 WEIGHT: 4.00kg
 SHEET 1 OF 1

SIZE: **B**
 DWG. NO.: SUB-ASSEMBLY 3-2
 REV: 0



NOTES
 1. DEBURR ALL SHARP EDGES

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	middle frame 1		2
2	middle frame 2		1
3	middle T bar		1

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

TOLERANCES:
 X = ± 0.05
 X.X = ± 0.03
 X.XX = ± 0.01
 ANGULAR = ± 1°

ALL DIMENSIONS ARE IN INCHES

MATERIAL
ENTER SPEC

FINISH
 6.3
INDICATE PLATING/COATING/ETC.

DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA
 MECH 4860 Engineering Design
 Department of Mechanical Engineering

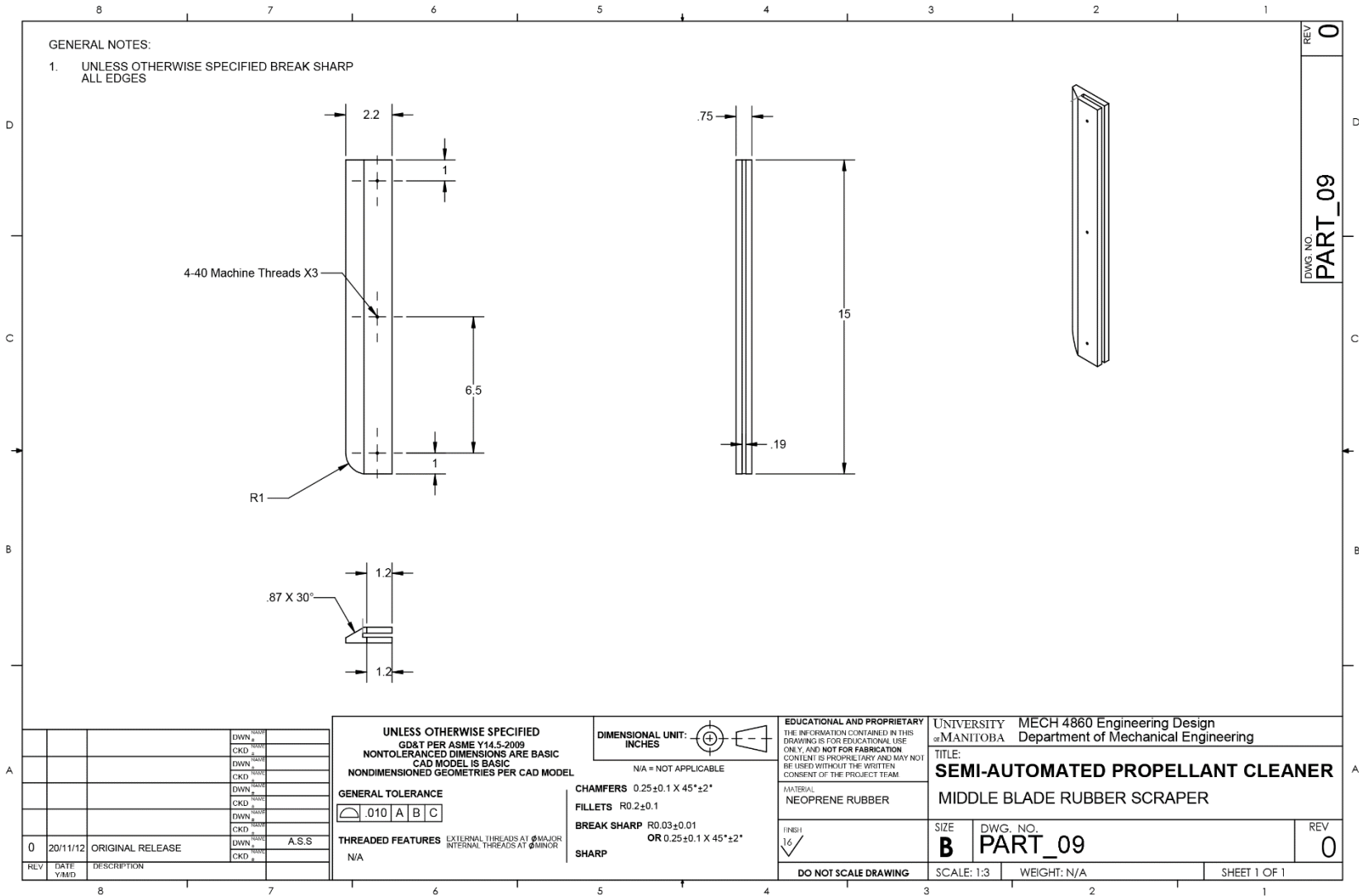
TITLE:
MIDDLE BLADE ASSY

SIZE **B** DWG. NO. REV **0**

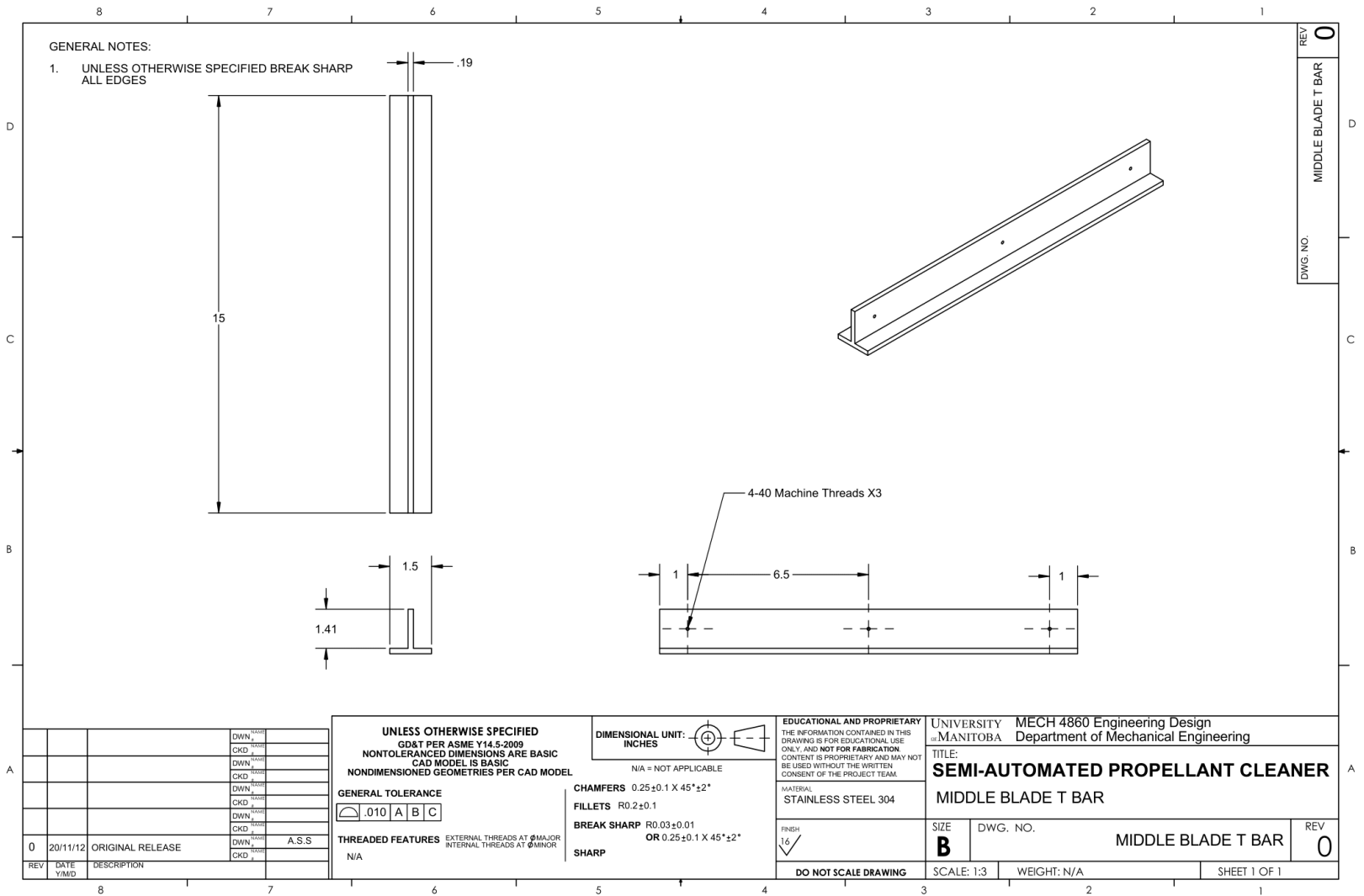
SCALE: 1:6 WEIGHT: N/A SHEET 1 OF 1

REV	DATE	DESCRIPTION	DWN CKD	DATE
0	20/11/30	RELEASED		

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REV 0
 DWG. NO. MIDDLE BLADE T BAR

			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
			CKD	
REV	DATE	DESCRIPTION		
	Y/M/D			

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT:
 INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 STAINLESS STEEL 304

FINISH
 1/6

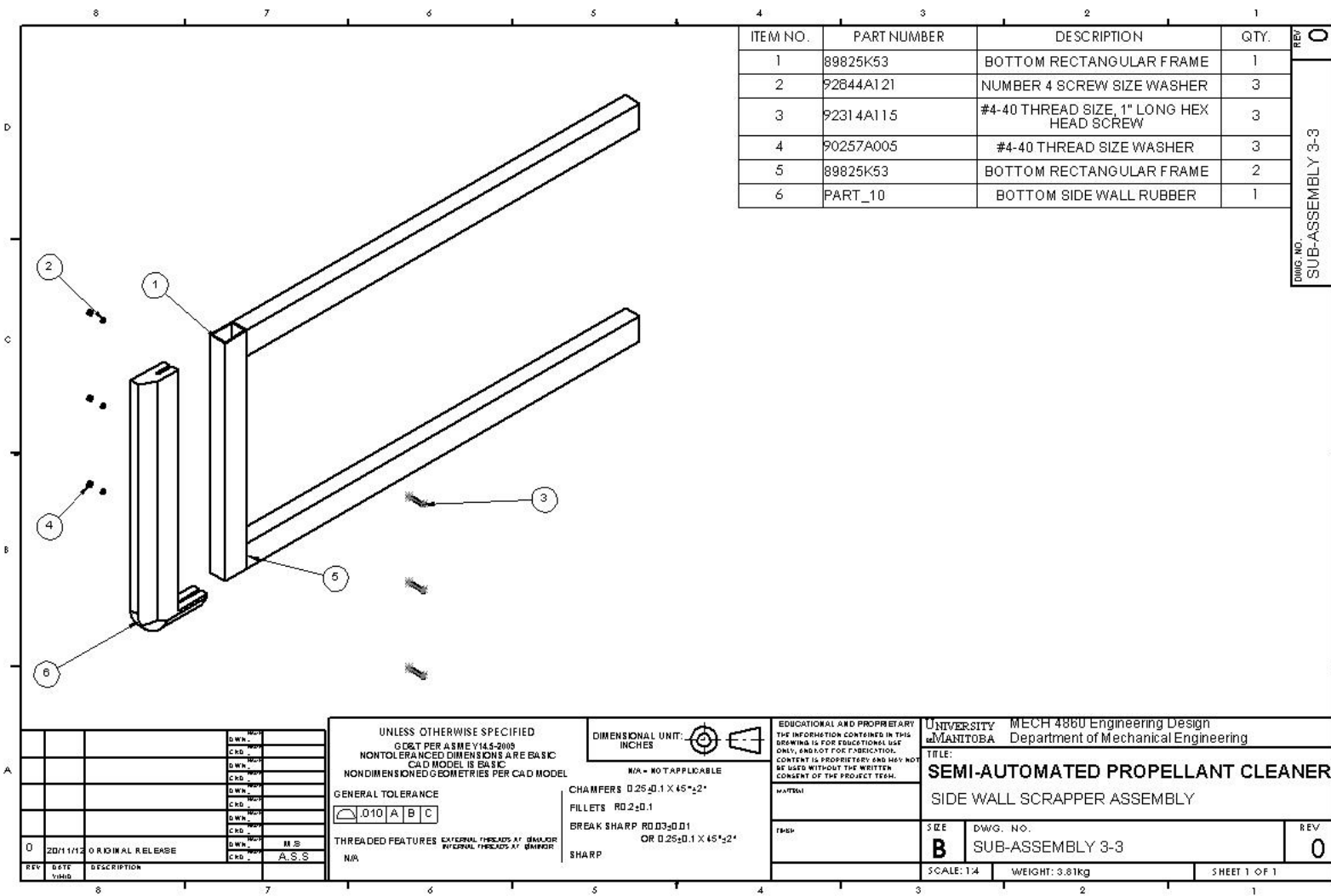
DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering

TITLE:
 SEMI-AUTOMATED PROPELLANT CLEANER
 MIDDLE BLADE T BAR

SIZE **B** DWG. NO. MIDDLE BLADE T BAR REV 0

SCALE: 1:3 WEIGHT: N/A SHEET 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	89825K53	BOTTOM RECTANGULAR FRAME	1
2	92844A121	NUMBER 4 SCREW SIZE WASHER	3
3	92314A115	#4-40 THREAD SIZE, 1" LONG HEX HEAD SCREW	3
4	90257A005	#4-40 THREAD SIZE WASHER	3
5	89825K53	BOTTOM RECTANGULAR FRAME	2
6	PART_10	BOTTOM SIDE WALL RUBBER	1

DWG. NO. SUB-ASSEMBLY 3-3
 REV 0

REV	DATE	DESCRIPTION	BY	CHKD.
0	20/11/12	ORIGINAL RELEASE		

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: INCHES
 N/A - NOT APPLICABLE

GENERAL TOLERANCE

THREADED FEATURES: EXTERNAL THREADS AT SHANK OR INTERNAL THREADS AT SHANK
 N/A

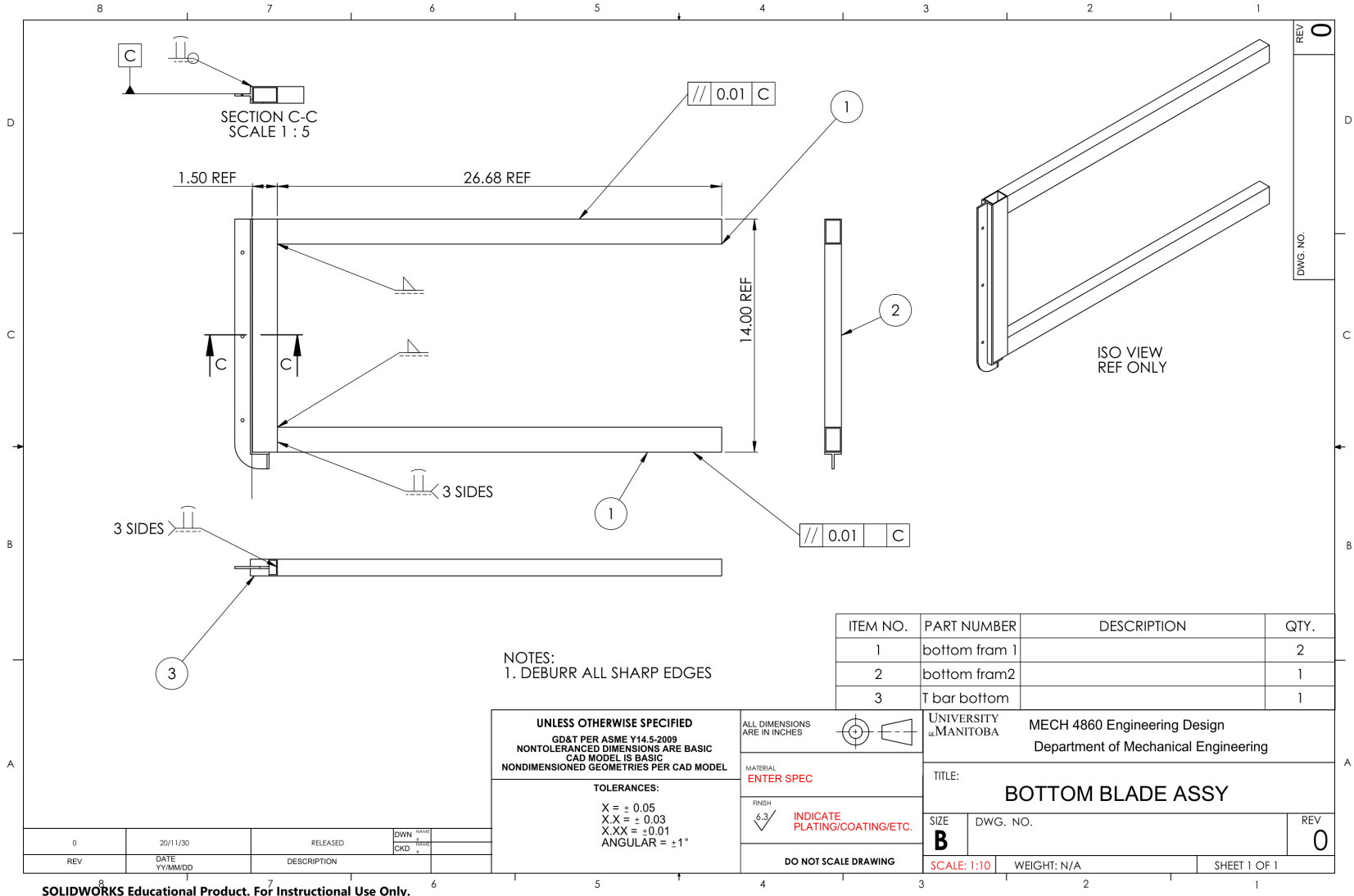
CHAMFERS: 0.25±0.1 X 45°±2°
 FILLETS: R0.2±0.1
 BREAK SHARP: R0.03±0.01 OR 0.25±0.1 X 45°±2°
 SHARP

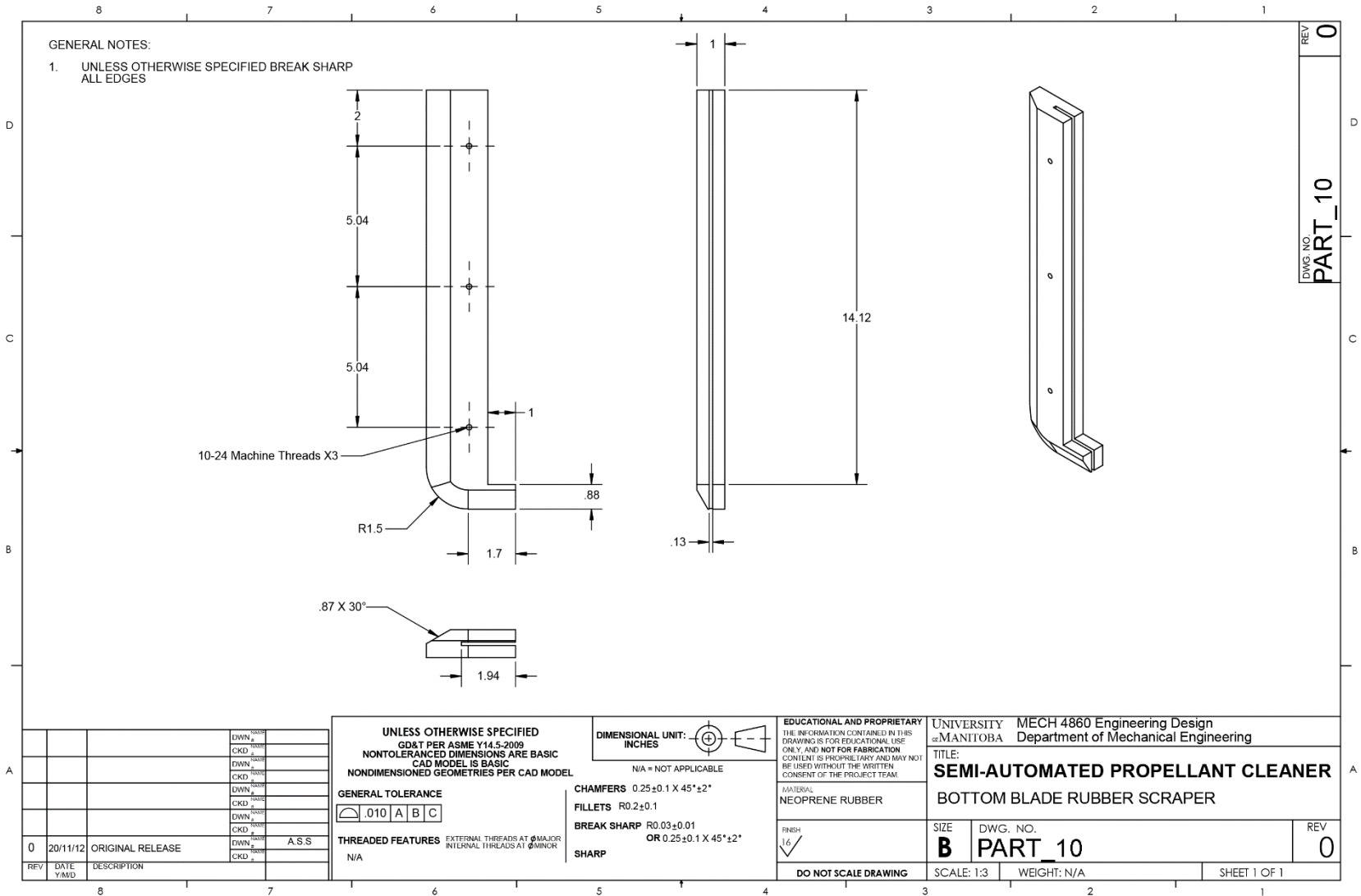
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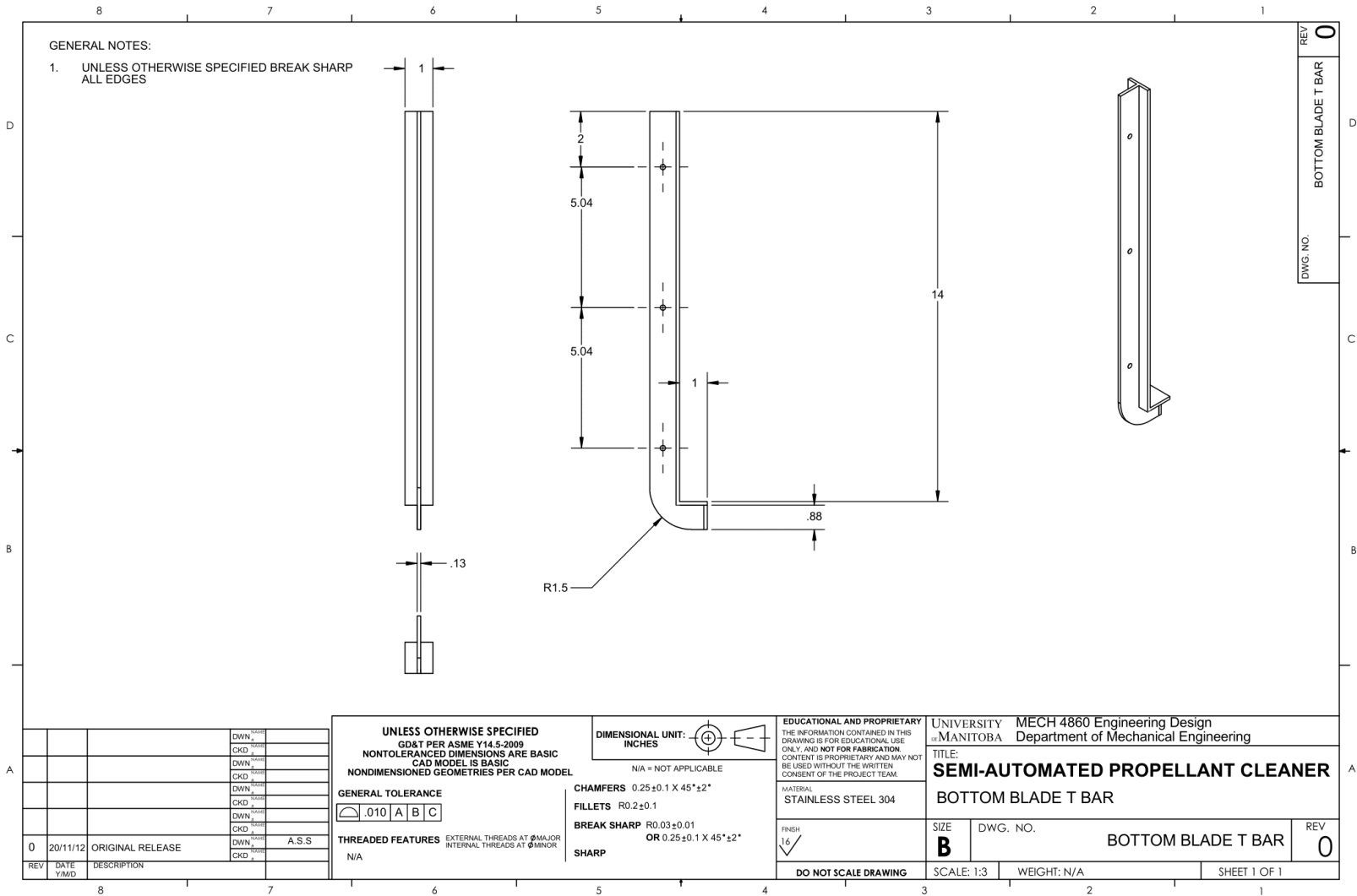
UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
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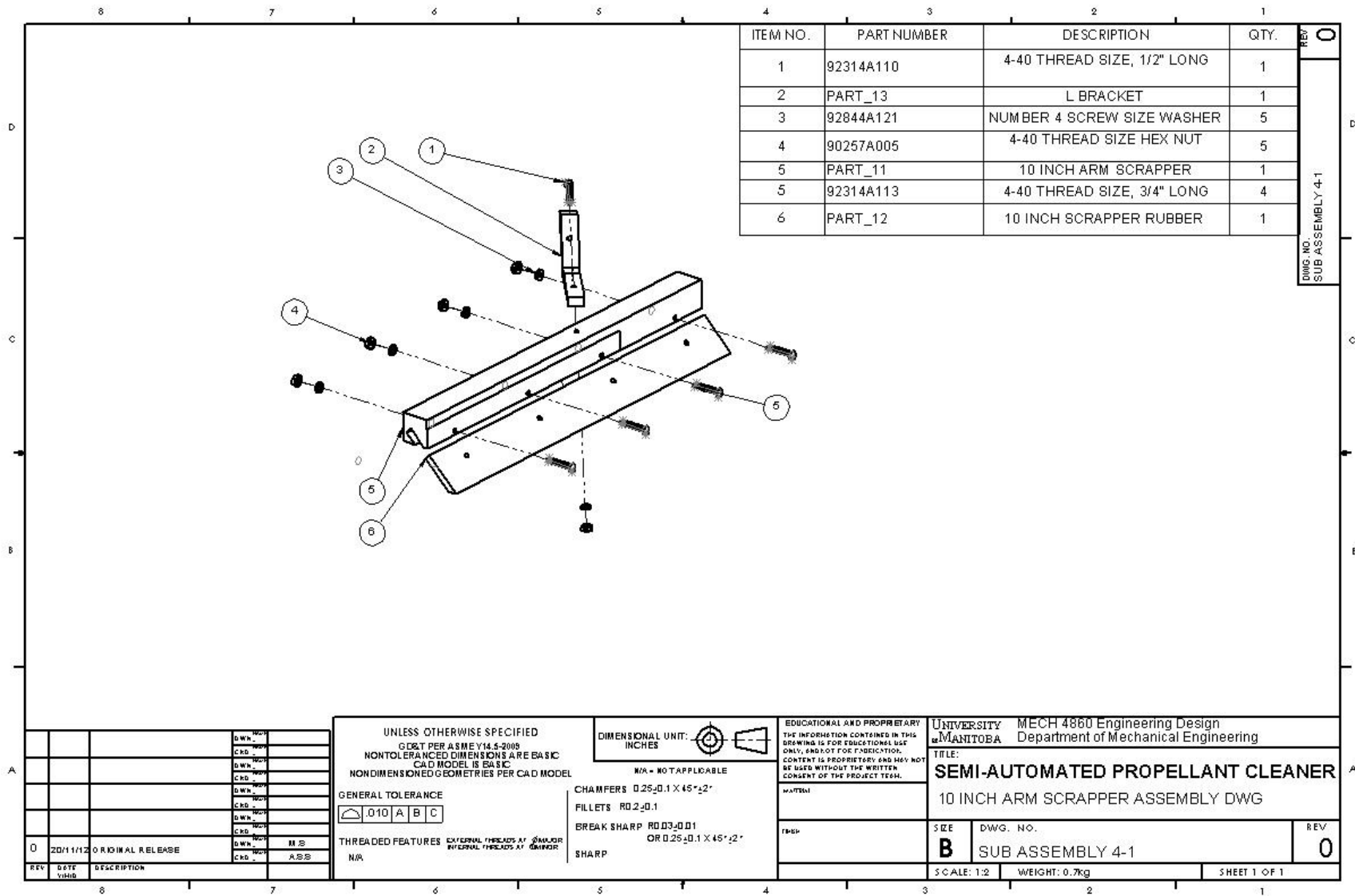
TITLE:
 SEMI-AUTOMATED PROPELLANT CLEANER
 SIDE WALL SCRAPER ASSEMBLY

SCALE: 1:4 WEIGHT: 3.81kg SHEET 1 OF 1







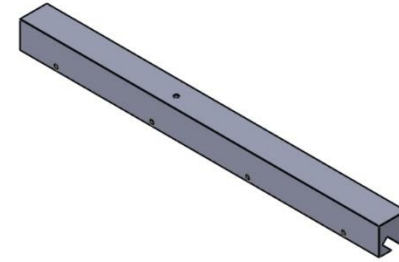
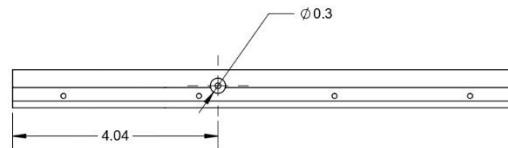
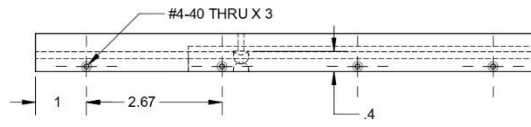
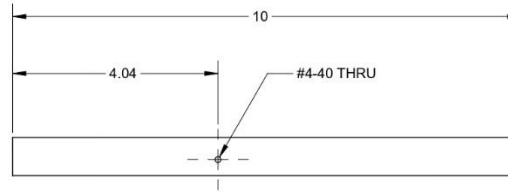
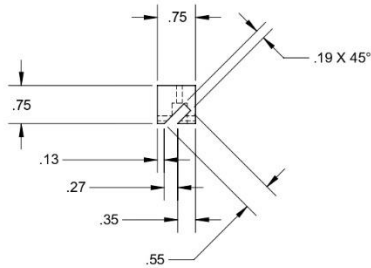


DWG NO. SUB ASSEMBLY 4-1
 REV 0

UNLESS OTHERWISE SPECIFIED GD&T PER ASME Y14.5-2009 NONTOLERANCED DIMENSIONS ARE BASIC CAD MODEL IS BASIC NONDIMENSIONED GEOMETRIES PER CAD MODEL		DIMENSIONAL UNIT: INCHES		EDUCATIONAL AND PROPRIETARY THE INFORMATION CONTAINED IN THIS DRAWING IS FOR EDUCATIONAL USE ONLY, AND NOT FOR FABRICATION. CONTENT IS PROPRIETARY AND MAY NOT BE USED WITHOUT THE WRITTEN CONSENT OF THE PROJECT TEAM.		UNIVERSITY OF MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering	
GENERAL TOLERANCE .010 A B C		CHAMFERS 0.25±0.1 X 45°±2° FILLETS R0.2±0.1 BREAK SHARP R0.03±0.01 OR 0.25±0.1 X 45°±2° SHARP		TITLE: SEMI-AUTOMATED PROPELLANT CLEANER 10 INCH ARM SCRAPER ASSEMBLY DWG		SIZE B DWG. NO. SUB ASSEMBLY 4-1 REV 0	
THREADED FEATURES N/A		THREADED FEATURES EXTERNAL THREADS AT $\frac{1}{2}$ MINOR INTERNAL THREADS AT $\frac{1}{4}$ MINOR		SCALE: 1:2 WEIGHT: 0.7kg SHEET 1 OF 1		DATE: 20/11/20 ORIGINAL RELEASE REV:	

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



REV 0
DWG. NO. PART_11

			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
REV	DATE	DESCRIPTION		
	Y/M/D		CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES
 N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 STAINLESS STEEL -316

FINISH
 1/6

DO NOT SCALE DRAWING

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 Department of Mechanical Engineering

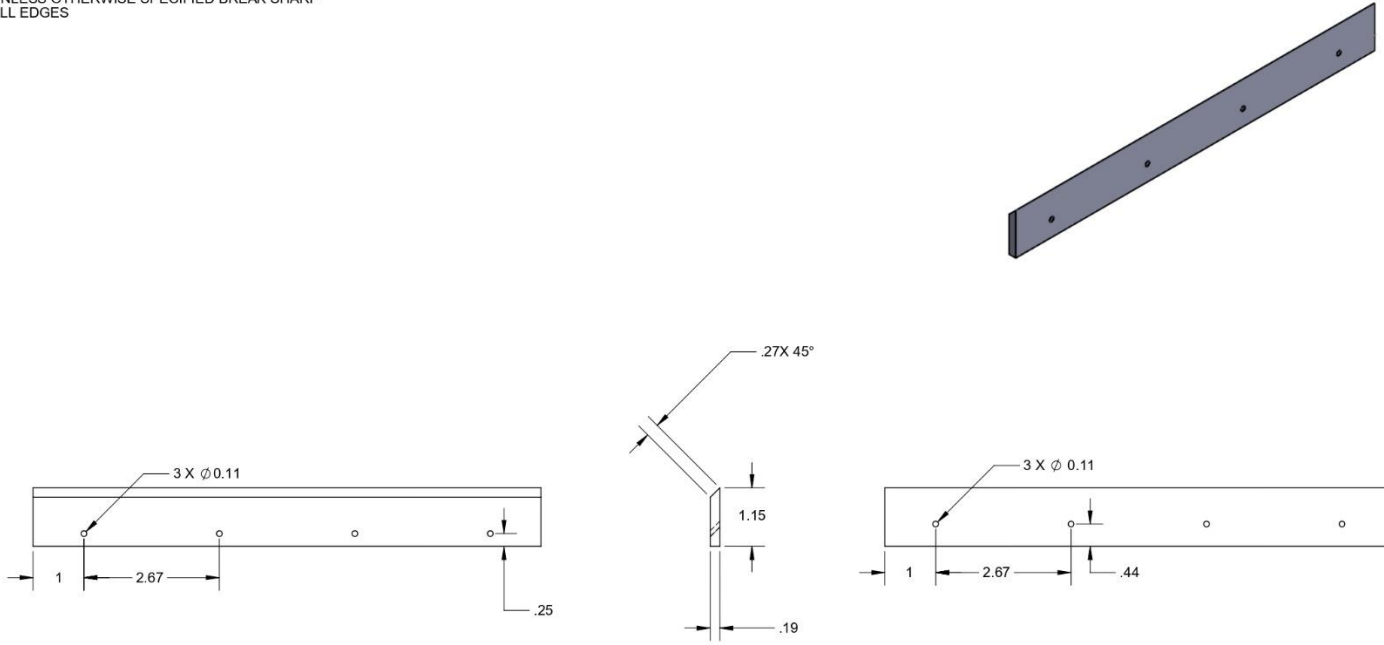
TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
10 INCH ARM BOTTOM SCRAPER

SIZE	DWG. NO.	REV
B	PART_11	0
SCALE: 1:2	WEIGHT: N/A	SHEET 1 OF 1

8 7 6 5 4 3 2 1

GENERAL NOTES:
 1. UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES

D
C
B
A



DWG NO. PART_12
REV 0

			DWN 0/2012	
			CKD 0/2012	
			DWN 0/2012	
			CKD 0/2012	
			DWN 0/2012	
			CKD 0/2012	
			DWN 0/2012	
			CKD 0/2012	
0	20/11/12	ORIGINAL RELEASE	DWN 0/2012	A.S.S
REV	DATE	DESCRIPTION	CKD 0/2012	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø/MAJOR INTERNAL THREADS AT Ø/MINOR
 N/A

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 BUNA-N RUBBER

FINISH
 16 ✓

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering

TITLE:
 SEMI-AUTOMATED PROPELLANT CLEANER
 10 INCH BOTTOM SQUEEGEE RUBBER

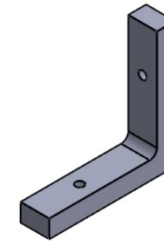
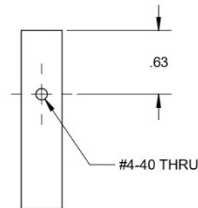
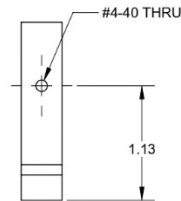
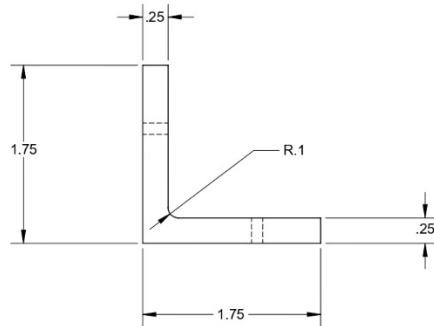
SIZE DWG. NO. **B PART_12**

DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 1

REV 0

GENERAL NOTES:

- UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES



REV 0
DWG. NO. PART_13

			DWG	
			CKD	
			DWG	
			CKD	
			DWG	
			CKD	
			DWG	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWG	A.S.S
REV	DATE	DESCRIPTION	CKD	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES
 N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 STAINLESS STEEL -316

FINISH
 1/6

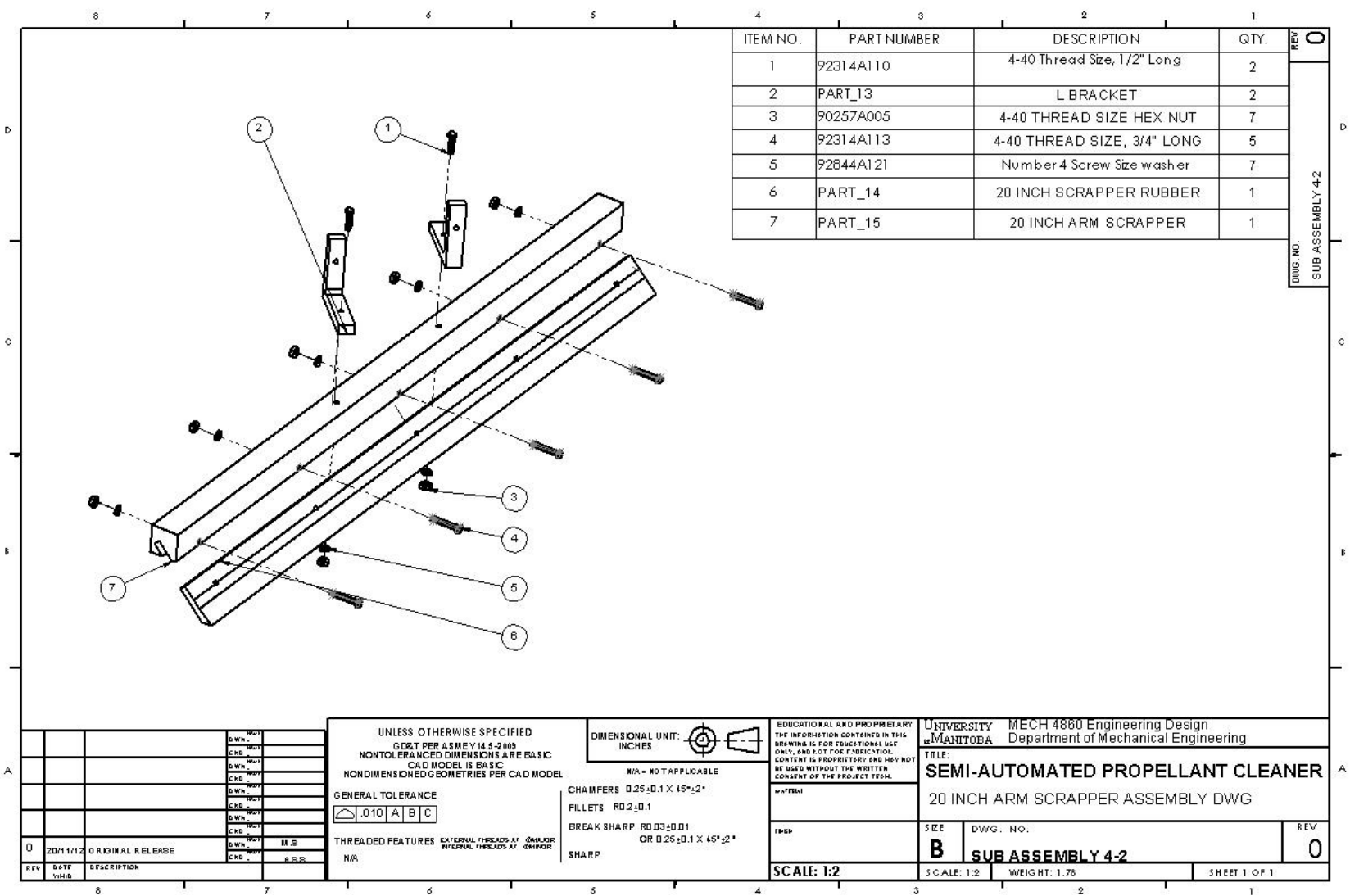
DO NOT SCALE DRAWING

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
L BRACKET
 BOTTOM BLADE L BRACKET

SIZE **B** **DWG. NO.** **PART_13** **REV** **0**

SCALE: 1:1 **WEIGHT:** N/A **SHEET** 1 OF 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	92314A110	4-40 Thread Size, 1/2" Long	2
2	PART_13	L BRACKET	2
3	90257A005	4-40 THREAD SIZE HEX NUT	7
4	92314A113	4-40 THREAD SIZE, 3/4" LONG	5
5	92844A121	Number 4 Screw Size washer	7
6	PART_14	20 INCH SCRAPER RUBBER	1
7	PART_15	20 INCH ARM SCRAPER	1

REV	0
DWG. NO.	SUB ASSEMBLY 4-2

REV	DATE	DESCRIPTION	DWG. NO.	REV
0	20/11/12	ORIGINAL RELEASE	M.S.	0
			R.S.S.	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASMEY 14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES

N/A - NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
 FILLETS RD 2±0.1
 BREAK SHARP RD 0.3±0.01
 OR 0.25±0.1 X 45°±2°
 SHARP

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SCALE: 1:2

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
 20 INCH ARM SCRAPER ASSEMBLY DWG

SIZE: **B** DWG. NO.: **SUB ASSEMBLY 4-2** REV: **0**

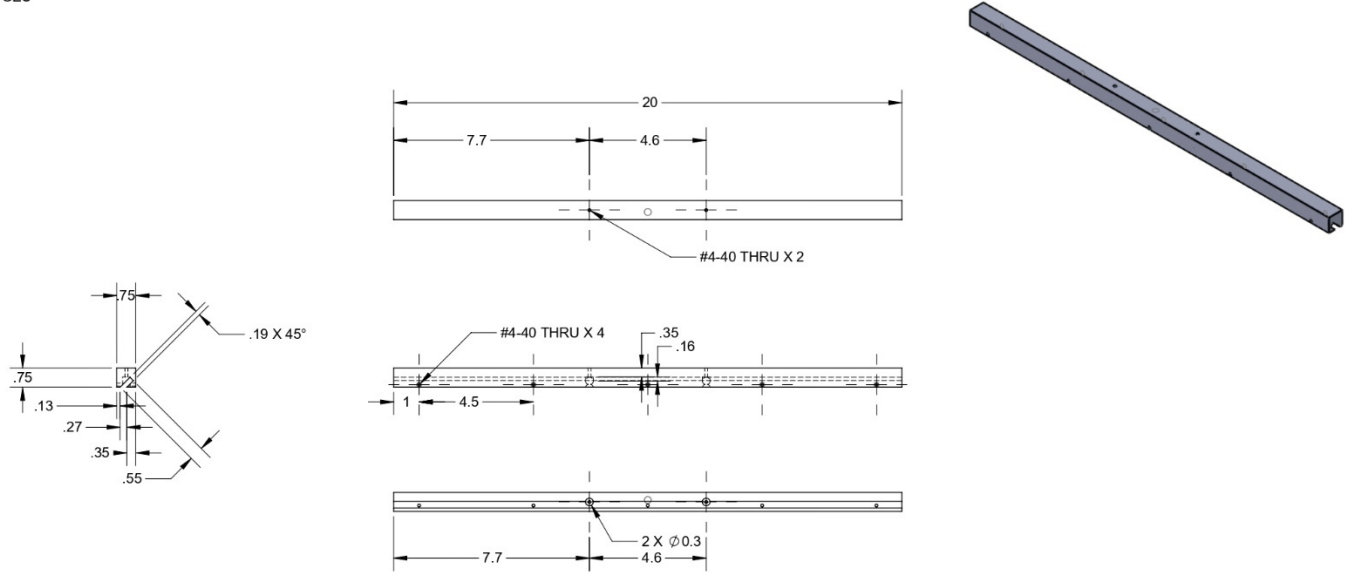
SCALE: 1:2 WEIGHT: 1.78 SHEET 1 OF 1

8 7 6 5 4 3 2 1

GENERAL NOTES:
 1. UNLESS OTHERWISE SPECIFIED BREAK SHARP ALL EDGES

D
C
B
A

REV 0
 DWG. NO. PART_14



			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
0	20/11/12	ORIGINAL RELEASE	DWN	A.S.S
REV	DATE	DESCRIPTION	CKD	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES
 N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL
 STAINLESS STEEL -316

FINISH
 1/6

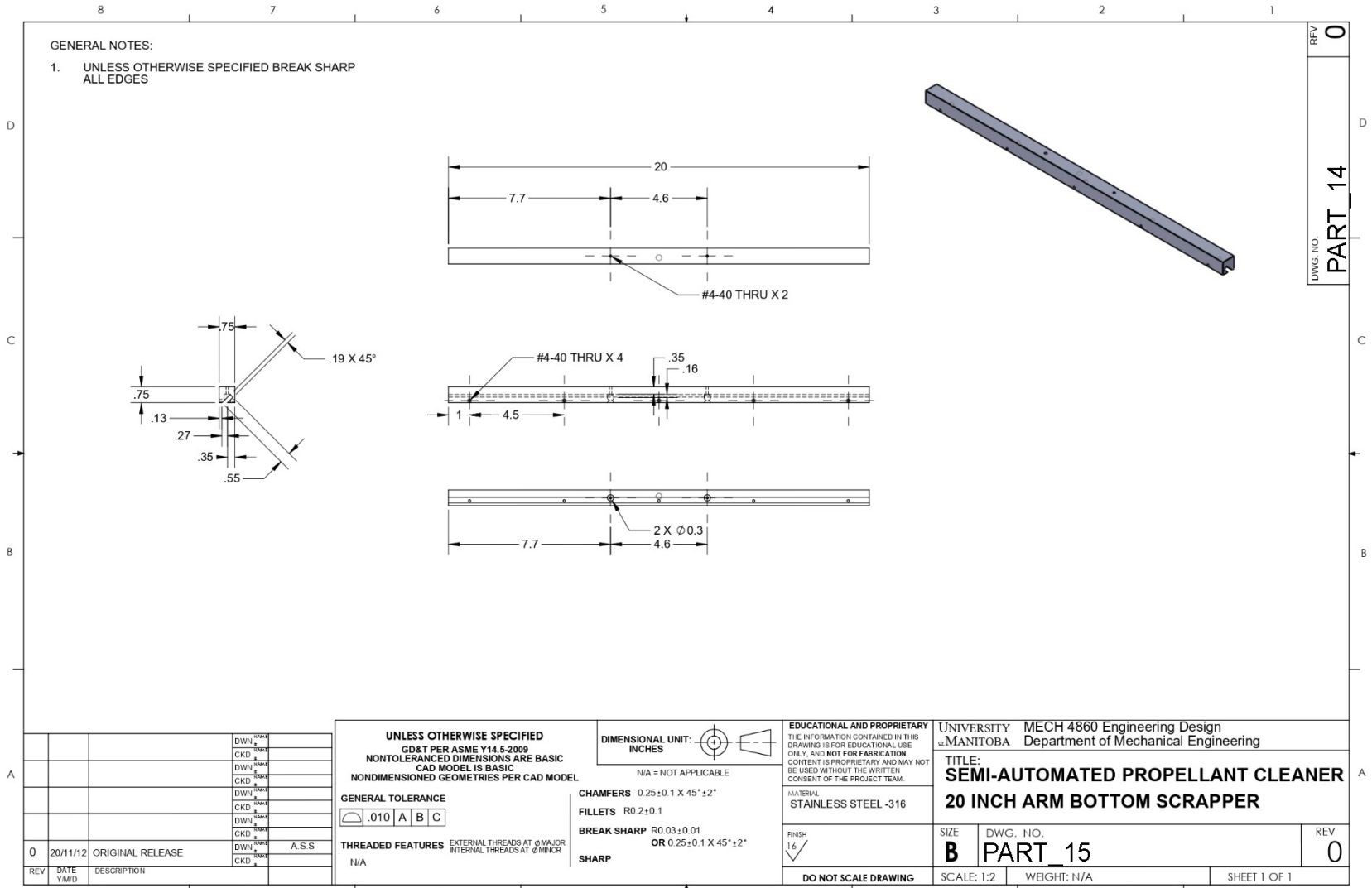
DO NOT SCALE DRAWING

UNIVERSITY of MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
 SEMI-AUTOMATED PROPELLANT CLEANER
 20 INCH ARM BOTTOM SCRAPER

SIZE B **DWG. NO.** PART_14 **REV** 0

SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 1



GENERAL NOTES:
 1. UNLESS OTHERWISE SPECIFIED BREAK SHARP
 ALL EDGES

REV 0
 DWG. NO. PART_14

REV	DATE	DESCRIPTION	DRAWN	CHECKED
0	20/11/12	ORIGINAL RELEASE	A.S.S.	

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 | A | B | C

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45°±2°
SHARP

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MATERIAL:
 STAINLESS STEEL -316

FINISH
 1/4 ✓

DO NOT SCALE DRAWING

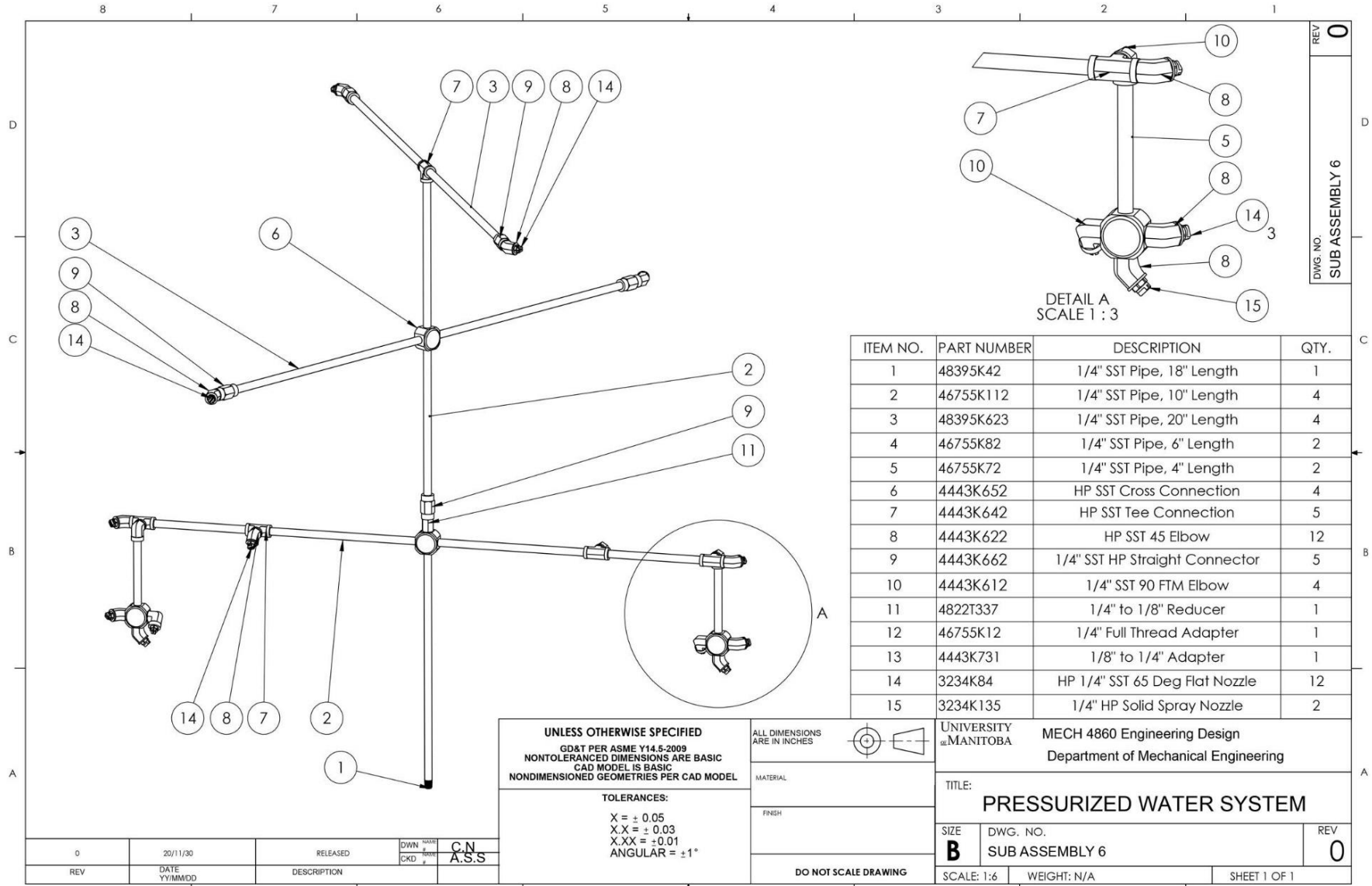
UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER
20 INCH ARM BOTTOM SCRAPER

SIZE **B** DWG. NO. **PART_15** REV **0**

SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 1

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REV 0
 DWG. NO. SUB ASSEMBLY 6

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

ALL DIMENSIONS ARE IN INCHES

MATERIAL

FINISH

DO NOT SCALE DRAWING

TOLERANCES:
 X = ± 0.05
 X.X = ± 0.03
 X.XX = ± 0.01
 ANGULAR = ± 1°

UNIVERSITY of MANITOBA
 MECH 4860 Engineering Design
 Department of Mechanical Engineering

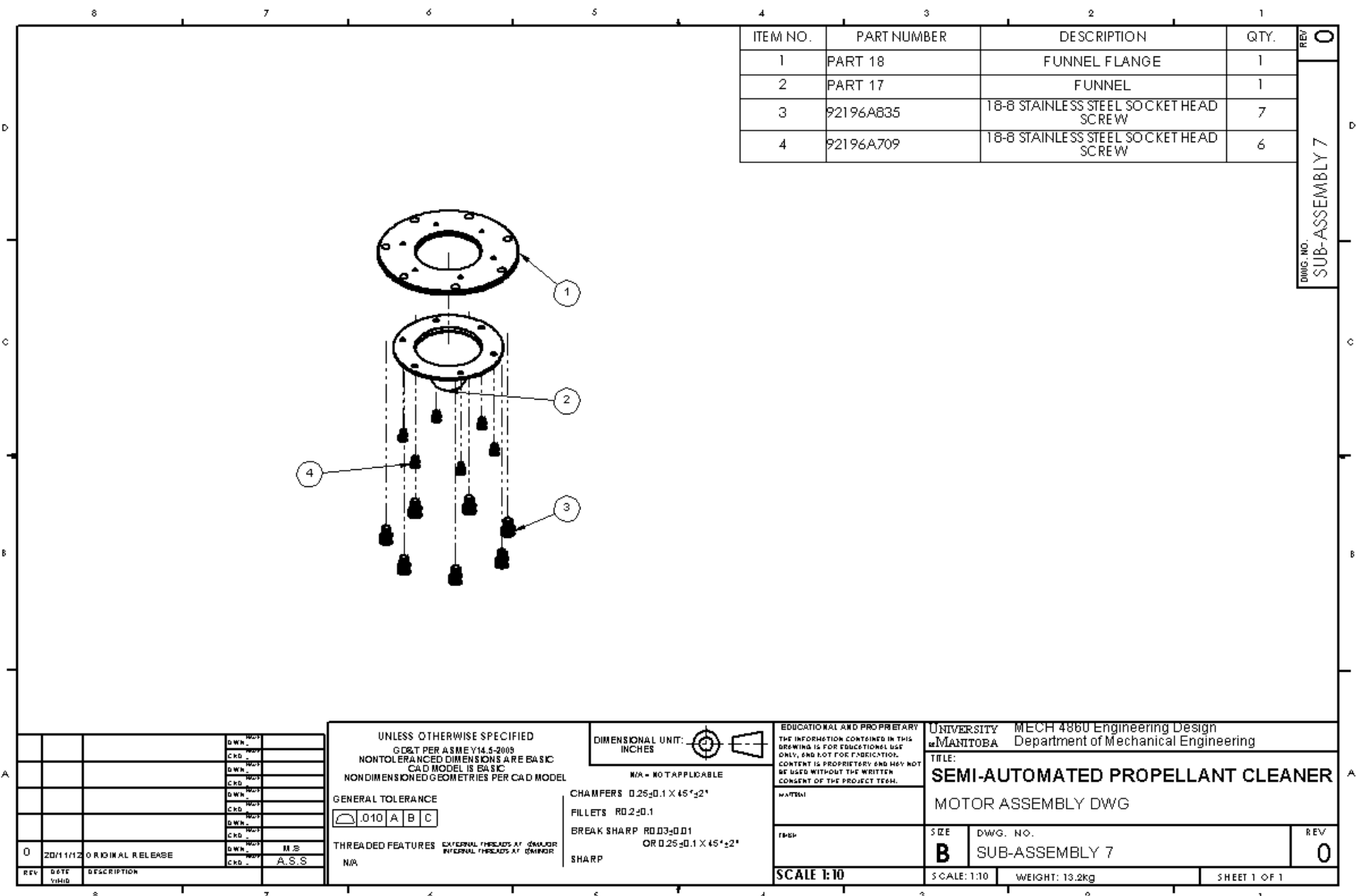
TITLE:
PRESSURIZED WATER SYSTEM

SIZE **B** DWG. NO. SUB ASSEMBLY 6 REV 0

SCALE: 1:6 WEIGHT: N/A SHEET 1 OF 1

0	20/11/30	RELEASED	DWN #	CKD #	C.N A.S.S
REV	DATE YYMMDD	DESCRIPTION			

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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	PART 18	FUNNEL FLANGE	1
2	PART 17	FUNNEL	1
3	92196A835	18-8 STAINLESS STEEL SOCKET HEAD SCREW	7
4	92196A709	18-8 STAINLESS STEEL SOCKET HEAD SCREW	6

REV	0
DWG. NO.	SUB-ASSEMBLY 7

REV	DATE	DESCRIPTION	BY	CHKD
0	20/11/12	ORIGINAL RELEASE	MS	ASS

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B C

THREADED FEATURES EXTERNAL THREADS AT 60° MAJOR
 N/A INTERNAL THREADS AT 60° MINOR

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45°±2°
 FILLETS R0.2±0.1
 BREAK SHARP R0.03±0.01 OR 0.25±0.1 X 45°±2°
 SHARP

EDUCATIONAL AND PROPRIETARY
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS FOR EDUCATIONAL USE
 ONLY, AND NOT FOR FABRICATION.
 CONTENT IS PROPRIETARY AND MAY NOT
 BE USED WITHOUT THE WRITTEN
 CONSENT OF THE PROJECT TEAM.

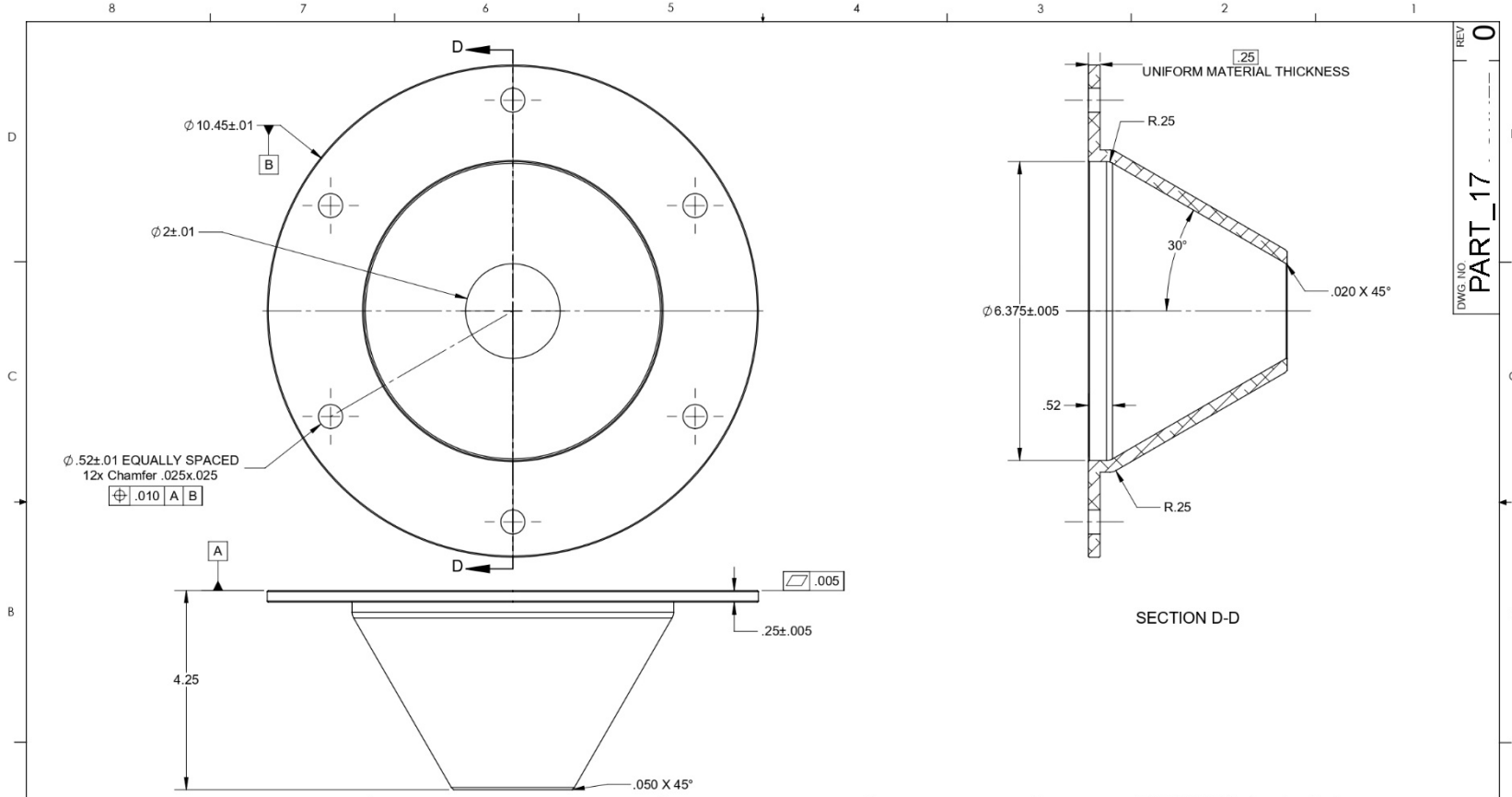
SCALE: 1:10

UNIVERSITY OF MANITOBA MECH 4860 Engineering Design
 Department of Mechanical Engineering

TITLE: SEMI-AUTOMATED PROPELLANT CLEANER
 MOTOR ASSEMBLY DWG

SIZE B DWG. NO. SUB-ASSEMBLY 7 REV 0

SCALE: 1:10 WEIGHT: 13.2kg SHEET 1 OF 1



REV	DATE	DESCRIPTION	BY	CHKD	DATE	DESCRIPTION
0	20/11/12	ORIGINAL RELEASE				

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONDIMENSIONED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 .010 A B

THREADED FEATURES EXTERNAL THREADS AT Ø MAJOR
 INTERNAL THREADS AT Ø MINOR
 N/A

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS 0.25±0.1 X 45° ±2°
FILLETS R0.2±0.1
BREAK SHARP R0.03±0.01
 OR 0.25±0.1 X 45° ±2°
SHARP

EDUCATIONAL AND PROPRIETARY
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MATERIAL
 ALUMINUM 6061-T6

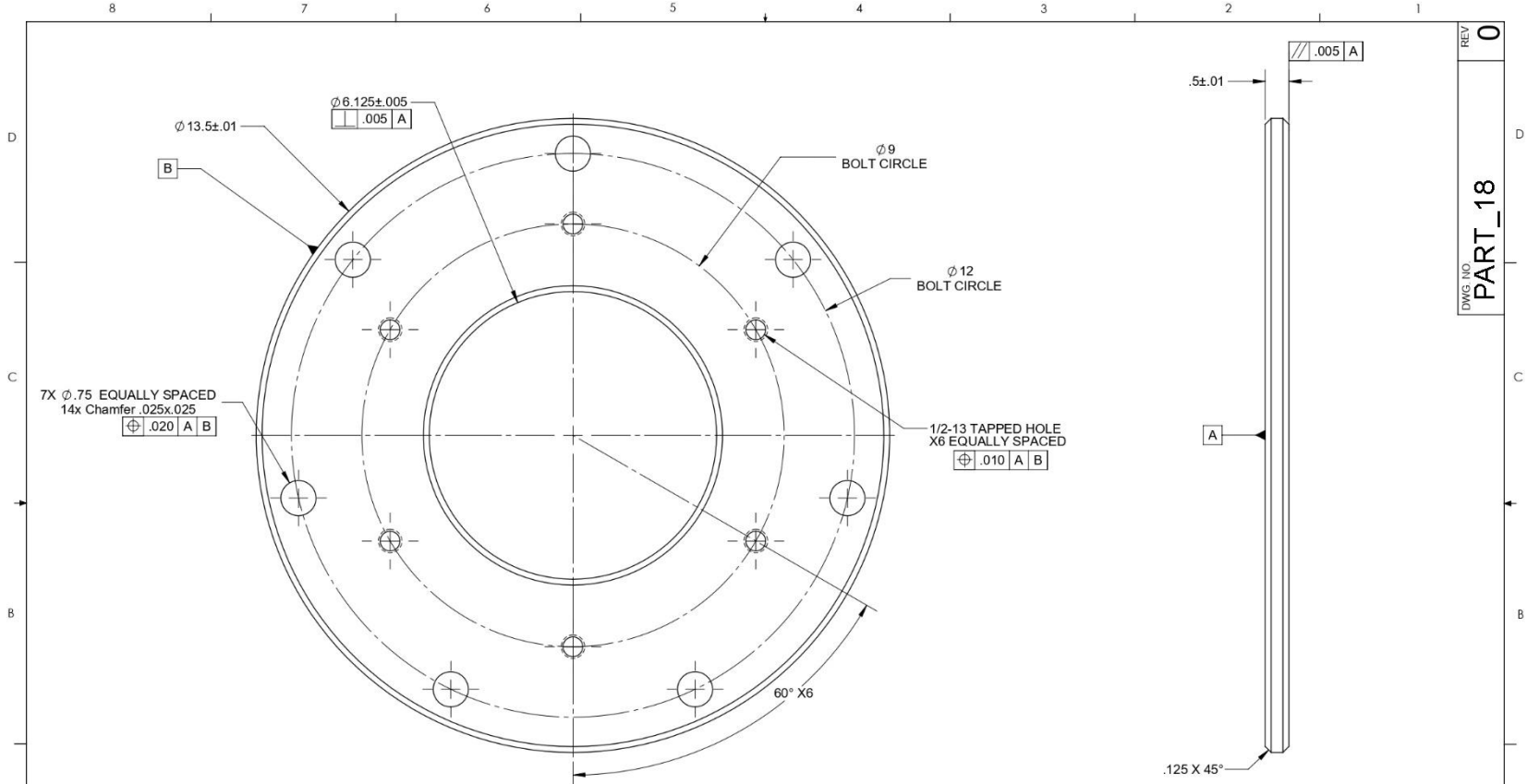
FINISH
 16 ✓

UNIVERSITY of MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering

TITLE:
 SEMI-AUTOMATED PROPELLANT CLEANER FUNNEL

SIZE B **DWG. NO.** PART_17 **REV** 0

DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: N/A SHEET 2 OF 2



DWG NO. PART_18 REV 0

REV	DATE	DESCRIPTION	BY	CHKD
0	20/11/12	ORIGINAL RELEASE		A.S.S

UNLESS OTHERWISE SPECIFIED
 GD&T PER ASME Y14.5-2009
 NONTOLERANCED DIMENSIONS ARE BASIC
 CAD MODEL IS BASIC
 NONTOLERANCED GEOMETRIES PER CAD MODEL

GENERAL TOLERANCE
 $\pm .010$ A B

THREADED FEATURES EXTERNAL THREADS AT ϕ MAJOR
 INTERNAL THREADS AT ϕ MINOR
 N/A

DIMENSIONAL UNIT: INCHES

N/A = NOT APPLICABLE

CHAMFERS $0.25 \pm 0.1 \times 45^\circ \pm 2^\circ$
FILLETS R0.2 ± 0.1
BREAK SHARP R0.03 ± 0.01
 OR $0.25 \pm 0.1 \times 45^\circ \pm 2^\circ$
SHARP

EDUCATIONAL AND PROPRIETARY
 THE INFORMATION CONTAINED IN THIS DRAWING IS FOR EDUCATIONAL USE ONLY, AND NOT FOR FABRICATION. CONTENT IS PROPRIETARY AND MAY NOT BE USED WITHOUT THE WRITTEN CONSENT OF THE PROJECT TEAM.

MATERIAL
 ALUMINUM 6061-T6

FINISH
 16

UNIVERSITY of MANITOBA MECH 4860 Engineering Design Department of Mechanical Engineering

TITLE:
SEMI-AUTOMATED PROPELLANT CLEANER FUNNEL FLANGE

SIZE B **DWG. NO.** PART_18 **REV** 0

DO NOT SCALE DRAWING SCALE: 1:2 WEIGHT: N/A SHEET 1 OF 2