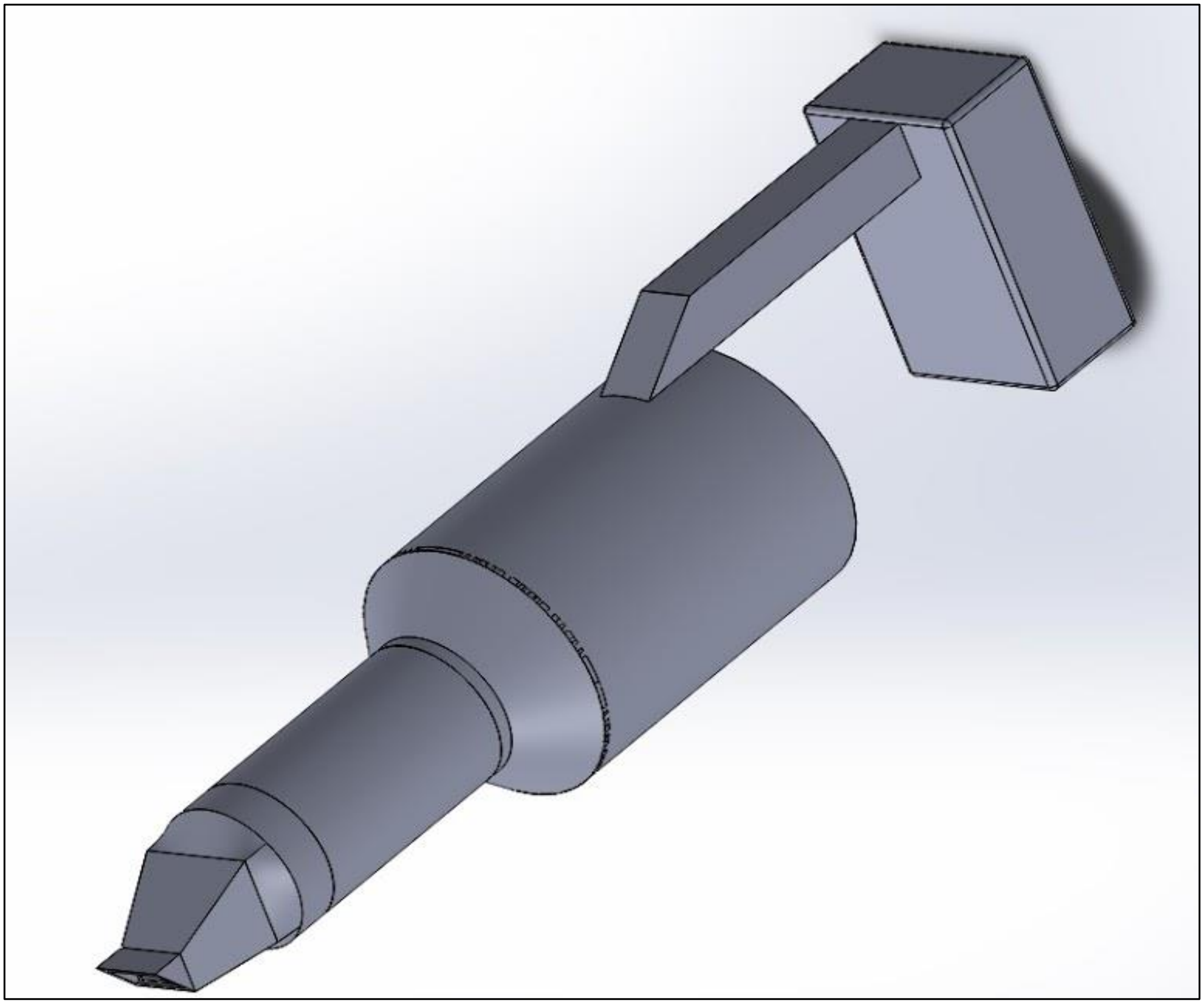
Rice Buster



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Executive Summary

There are three important factors that will make the Rice Buster excel against its competition. This cordless vacuum cleaner will have strong suction, extended battery life and durability. The goal is to create a light weight product that will perform simple cleaning tasks. The Rice Buster is a handheld vacuum that is compact enough to be used and stored in a car, dorm room or an apartment. This product can be manufactured for $24.66, and will be sold for an affordable price of $50. The investment is valued at $1.45 million after four years, netting over $500,000 in profit per quarter after the break-even point. The Rice Buster targets a college-aged audience that will want a low cost vacuum to accomplish simple vacuuming tasks.

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1. Introduction

1.1 Problem Statement

The overall goal was to design a handheld cordless vacuum that could perform simple tasks such as suctioning grained rice. The product will be created using a 20V cordless drill and an allowance of $30. The Rice Buster should be capable of suction and storage of uncooked grains of rice. The Rice Buster should be marketed near college campuses such as Penn State University. There are roughly eight-thousand new under-graduates that come to Penn State University Park yearly[1]. This creates an annually recurring population of potential customers for the Rice Buster.

1.2 Background Information

A vacuum cleaner is comprised of six essential parts: an air intake, an air exhaust, a fan, a motor to drive the fan, a battery to power the motor, and a filter. The air intake for a handheld vacuum cleaner can be small, as the objective is not to pick up large objects. A small intake area will create more suction for the vacuum. The air exhaust will be slightly larger than the air intake, allowing air to exit the housing freely without loss of energy. An axial fan must be used to create suction for a vacuum. This fan will be capable of creating a large pressure difference, creating a partial vacuum and suction needed for the vacuum to perform properly. A tight fit with the housing around the fan is important to maintain suction. The motor and power source used to drive the fan is the same one which powers the cordless drill provided. It is capable of delivering 20V to the motor. According to the dynamometer drill test, the battery voltage should remain constant and is capable of a maximum power of 58.2 W. The filter is necessary to strain all debris from the air before reaching the fan.

1.3 Project Planning

Project Planning describes the overall design process and project management structure. The Rice Buster will be available for purchase by the holiday season. Some of the constraints consist of using the same motor and battery given with the cordless drill and a $30 budget. The next phase is concept development to gather customer needs, identify lead users and research competitive products. Researching patents and benchmarking competitive products are useful to get a clear idea of what the Rice Buster must be able to accomplish. Creating concepts is another crucial part of this phase. A concept selection matrix will screen the aspects found in the customer needs and select the highest rated concepts. The Rice Buster’s functional aspect and geometric layout will be defined. There will be estimations to how the product will perform and how much the product will cost. Detail design will proceed and describe the manufacturing details of the Rice Buster. Drawings and descriptions will have to be detailed enough for a manufacturer to be able to comprehend and produce the product. Next testing and refinement will test the overall performance, reliability and durability of the product. A Gantt chart in appendix A describes the tasks that need to be completed and each team member’s role.

2. Customer Needs and Specifications

2.1 Identification of Customer Needs

From a Facebook survey that consisted of 24 participants, ranging from age 18-50, it was determined that there were several properties that a vacuum should have and several others that were not very important. See Appendix I for the survey. The survey was posted on three separate Facebook accounts to attract people from different backgrounds. A few participants were over 25 years old, but the majority were college-aged (18-25). Equal amounts of each gender also responded to the survey, 14 females and 10 males. The results of the Facebook survey determined the seven important properties that would be incorporated into the design of the Rice Buster (battery life, suction, durability, weight, ease of emptying, cost, and size). The following five properties were listed in the survey and participants were asked to rank each one on a scale of 1-5 (1 being least important and 5 being most important): long battery life, suction, durability, lightweight, and ease of emptying. The most valued property was suction with an average score of 4.92. This was followed by long battery life with 4.04, durability with 4.0, lightweight with 3.42, and ease of emptying with 3.17. From this ranking it was determined that participants valued a vacuum that functioned well and had a high durability more than they valued its weight or ease of emptying. The survey also supported the fact that the vacuum needed to be very reliable (high quality); this was more important than being low cost. Four of the participants also noted in the final question that size/compactness was very important. So from the results of the survey, we determined that college students would be our target market and we would design a compact, high-quality vacuum to fit their needs. Half of the participants of the survey stated that they would like a vacuum with multiple attachments, but since the vacuum was going to be low cost this would be hard to achieve. Aesthetics were also determined to be of very little importance from one of the last questions on the survey; we could only assume this was because most of the participants would rather have a well-functioning vacuum rather than a good-looking vacuum. However, this could be identified as a latent need because it is something that customers do not take notice of when they are using the vacuum, but they probably would not buy the vacuum if it did not look like it was put together neatly.

2.2 Design Specifications

The two categories that received the most attention in the Facebook survey were long battery life and strong suction. The power of air flow determines if the vacuum works properly. Also, electric power is important to long battery life because the battery needs to be efficient. Using the results from drill tests, the optimal running speed of the motor was determined to be 778 rpm; however, this was with the transmission attached that reduced the rotational speed and increased the torque. The gear reduction from the transmission was 1:5; therefore, the optimal running speed of the motor after removing the transmission was 3890 rpm. The weight of the product is important to customers because they should be able to hold the vacuum with one hand. This is why the vacuum needs to be lightweight. The size of the vacuum has to do with durability. The product should be compact, but smaller pieces would be easier to break. A balance of size and durability has to be reached so that the vacuum is small enough to maneuver yet durable enough to be able to bump into objects and not break. Filter quality is significant to durability as well. There needs to be a mesh layer to stop larger objects so it will not jam the system. Also, the filter quality will affect the suction so it is important that the filter allows the passage of air. Aesthetics may determine what kind of material is going to be used, thus affecting the overall weight. The ergonomics of the product is important to how a user will empty the contents of the vacuum. The type of collection chamber can determine whether the vacuum gets strong suction and how simple it is to empty the vacuum. The switch method can effect battery life and durability. The type of switch should limit the amount of time the battery is on. Lastly, since the switch will be used often, the durability of the switch is important. The QFD chart is shown in Appendix C.

The metrics are rated on a scale from 1 to 5. A survey identified customer needs, see Appendix E. Taking the customer needs into account, the weights are ultimately determined by team consensus. Power is directly related to the suction and the customer needs strong suction. Weight affects the overall feel and usability of the product, but the objective can still be met with excess weight. Size has a weight of 3, being very similar to weight. The customer ranked filter quality as very important to a marketable vacuum cleaner. Aesthetics is not very important to the customer or to the design team. Ergonomics is also not very important to the customer based on the customer needs survey. The size of the collection chamber is important to the customer. The objective requires a collection chamber to store the grains of rice. The vacuum needs to be turned on and off to meet the objective, but is not as important as the suction of filtering mechanisms.

Weighted Chart of Metrics

Metric	**Weighting**
Power	5
Weight	3
Size	3
Filter Quality	4
Aesthetics	2
Ergonomics	2
Collection Chamber	4
Switch Method	3

3. Concept Development

3.1 External Search

Patent Search-

Black and Decker patented and published their design of a cordless vacuum cleaner in 1977. They claim their design includes a nozzle at the inlet for air to come in leading to a constant cross section until reaching a diffuser in order to increase airflow. They also claim that their design is a battery pack leading to a switch that controls the circuitry and in turn powers the motor that drives the fan.[2] The Rice Buster would seriously be constrained by this patent. Luckily, patents are valid for 20 years and the Rice Buster will not be infringing on Black and Decker's patent. The battery that will be used runs to a switch which in turn powers the motor and drives the fan to create suction. Also, the tube that will be used in the Rice Buster should be made to increase air flow which is done by having a smaller inlet cross section and a wider air outtake cross section. This is very similar to the Black and Decker patent but with this constraint, it would be hard to create a cordless vacuum that does not infringe on their patent. The Rice Buster will be a profitable item, people will want to buy this vacuum so the project will move forward even though the design for the Rice Buster could possibly be infringing on the Black and Decker's patent for a cordless vacuum cleaner.

Black and Decker seems to control the cordless vacuum patents. A few years after they patented the cordless vacuum cleaner idea, they patented a power brush tool attachment in 1989. They claim their design uses a brush attachment to use across a surface.[3] Customer needs show that the need for an attachment was a split decision. The patent search helps to describe how the suction works and what is already been invented so that it is not imitated. Again, patents are valid for 20 years so a brush tool attachment would not infringe on Black and Decker's patent. Sometimes it is hard to design a product such as the Rice Buster without using many of the ideas that Black and Decker patented in their cordless vacuum cleaner patent.

Benchmarking-

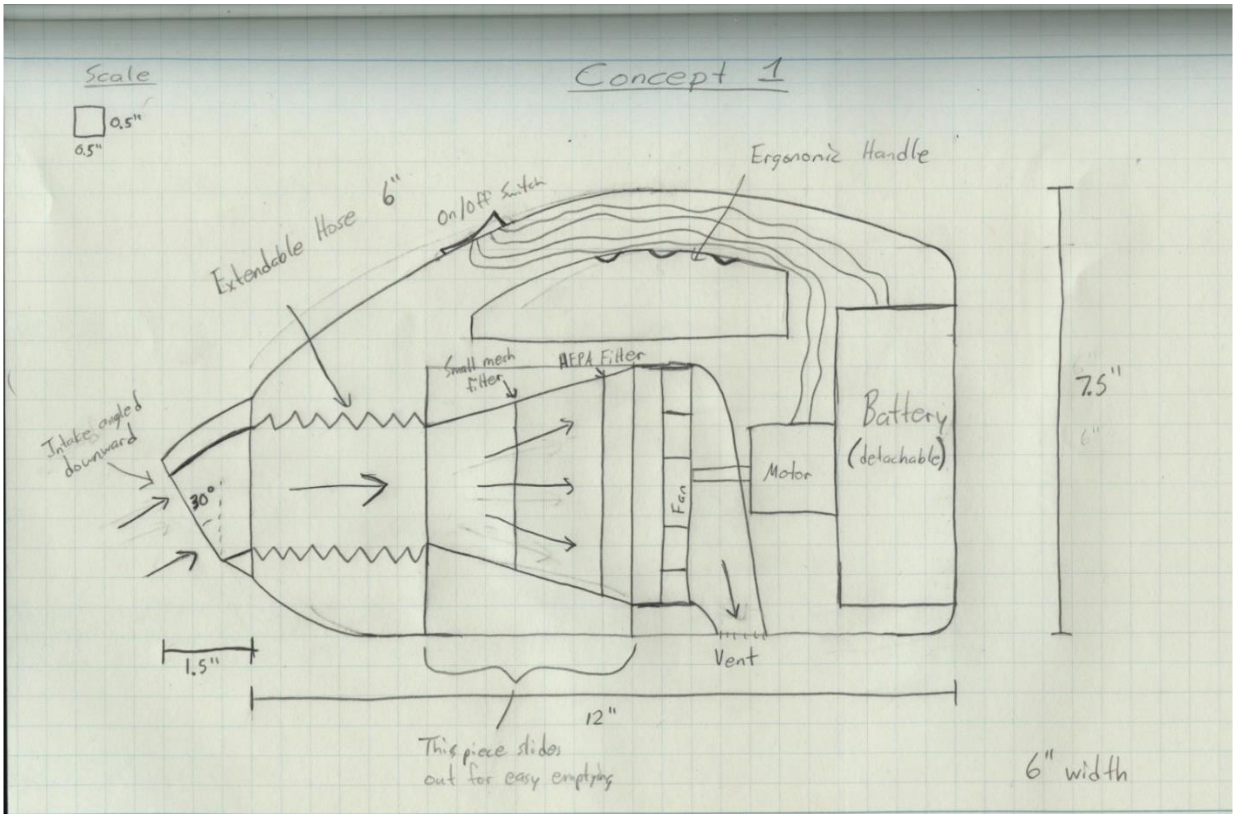
Five different handheld vacuum cleaners were examined for benchmarking purposes. The eight metrics defined in the QFD chart were used to compare the products. The categories of battery life, durability, and price have been added, as they are important to differentiate the products. These categories are not used as metrics for concept selection because the concepts use the same battery and motor system, and they are constrained by a $30 budget. Ergonomics cannot be measured within the scope of this benchmarking, as the vacuums would need to be purchased to get a feel for the product. These products did not disclose an exact debris collection chamber size. These vacuums range from $149.99[4] to $44.22[5]. All are under 10 lbs and smaller than 60 cubic feet in size. All cordless vacuums run from 18V to 22.2V. The Dyson DC34 had the best performance in the benchmarking chart; it is the lightest, most powerful, best looking, and most durable of the five products. It is also the second smallest and has the second longest lasting battery. It is also the most expensive vacuum on the list. The Dyson is at the top of the field and is the best product for comparing performance standards. See Appendix D.

3.2 Problem Decomposition

The vacuum can be separated into three distinct sub-systems: See Appendix D for black box.
A) Suction: First power is drawn from the battery, supplying voltage and current. The voltage and current power the DC motor, turning a shaft with a maximum power of 58.2 Watts. The shaft spins the fan blades, accelerating the air and creating a pressure difference between the front and back of the fan. This pressure difference creates a partial vacuum, creating suction.
B) Air Filtering and Debris Collection: Air and debris enter the inlet using the suction created by sub-system A. Then the debris must be separated from the air using a filter or series of filters. The debris will deposit in the chamber in front of the filter, while the clean air exits the system through an outlet.
C) Signal: The vacuum must be able to turn on or off easily. To activate the vacuum, the user will turn a switch to the 'on' position, closing the circuit connecting the battery to the motor. This completed circuit will supply voltage and current to the motor. To turn off the vacuum, the user must turn the switch to the 'off' position, cutting off the power supply.

3.3 Concept Generation

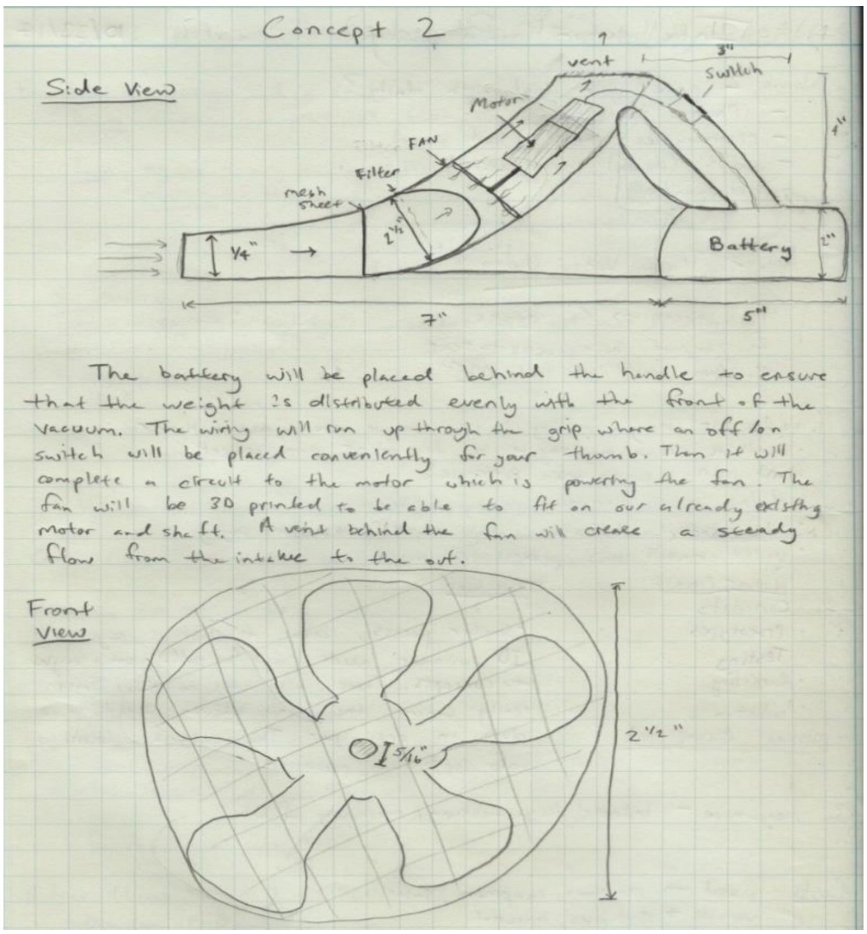
Concept 1-



This concept features a 13.5 inch x 7.5 inch x 6 inch handheld vacuum. The battery is detachable, for recharging purposes, and snaps into place in the rear of the vacuum. The motor that was taken from the handheld drill sits just in front of the battery and has a shaft running into the suction chamber that connects to the fan. The fan creates a low pressure area inside of the suction chamber which brings the dirt and air in the front; the clean air exits through the vent on the underside of the vacuum. Inside the suction chamber there are two separate filters that can easily be cleaned when the debris is emptied from the chamber. The first filter is a strong piece of fine mesh that catches all of the large debris, and the second filter is a fine cloth filter that collects all of the dust. This makes the filtering capability better and prevents the filters from clogging. The intake on the front of the vacuum is angled downward 30° so that the vacuum can be held at a comfortable angle instead of at 90°. Behind the intake piece there is a three inch long hose that can extend to six inches to allow the user to reach difficult areas. The on/off switch is located at the top of the handle. It is a switch that can be set to the on or off position and does not need to be continuously pressed while the vacuum is in use. The handle is rubberized and molded to fit a human's hand on the underside, which allows for a more firm and comfortable grip.

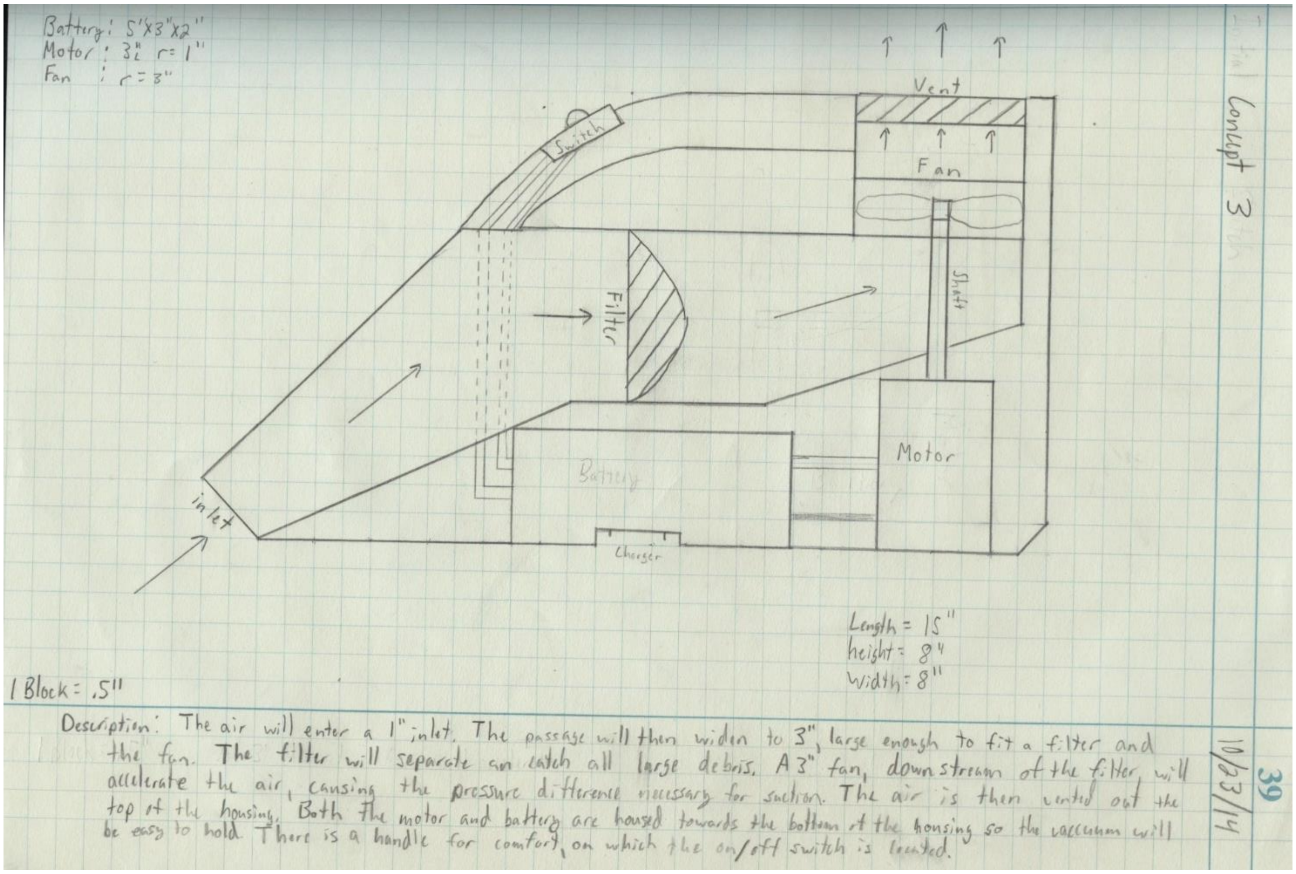
The suction chamber is in the shape of a cone and narrows near the inlet so that the air is moving at a greater velocity; this will improve suction. The vent is angled downwards so that air is blowing directly away from the person using the vacuum. A portion of the chamber slides out of the bottom of the vacuum so that emptying the debris is very simple. The intake on the front of the vacuum is angled downward 30° so that the vacuum can be held at a comfortable angle instead of at 90°. Behind the intake piece there is a three inch long hose that can extend to six inches to allow the user to reach difficult areas.

<u>Concept 2</u>-



The idea for concept 2 was to distribute the weight evenly to create a sturdy feel to the vacuum. An ergonomic handle angled at 45 degrees would allow the user to be comfortable using the vacuum. The customer needs showed that they wanted strong suction, so a continuous air sealed tube would run along the top of the vacuum at an angle allowing for maximum suction. The diameter of the tube would be 2 and a half inches to allow for compactness which is what the customer wants.

Concept 3-



This concept was conceived using prior knowledge of vacuum systems with the goal of user comfort. The objective of concept three is to put as much of the weight as possible towards the bottom of the housing and to distribute the weight evenly. This balance allows the user to handle the vacuum easily. The rest of the design is built around the placement of the motor and the battery. Air and debris enter through a small circular inlet one inch in diameter. This passage widens to three inches to fit the fan and a filter. The filter is comprised of a mesh bag cut to fit the passage. There will be some give to the mesh to secure debris. A three inch diameter fan is powered by the motor, creating the pressure difference necessary for suction. The air exits through a vent directly behind the fan. The motor is powered by a 12V battery connected to a switch. This switch is placed on the handle for accessibility.

3.4 Concept Selection

Decision matrices are used to compare design elements of concepts one, two, and three. Each specification is given a rank on a scale from one to five, then multiplied by the weighting factor for that specification. The weighted scores are summed to determine a winner. If a specification is not relevant to the subsystem being analyzed, a score of zero will be assigned to all concepts for that specification. Power is ranked by analyzing the size of the fan used in the design and the number of elbows and turns for the airflow. Weight is ranked by the approximate weight of all components of the system or subsystem. Size is ranked by the approximate volume of all the components of the system or subsystem. Filter quality is determined by the number of filters used in the design, type of material used, and size of the mesh. Aesthetics is determined by team consensus. Ergonomics is determined by team consensus considering the ease of use for the customer, including factors such as weight distribution, balance, feel, and simplicity. The collection chamber is ranked based on how much debris the chamber can hold and how easy it is to empty the chamber. Switch method is ranked by considering the position of the switch on the vacuum and the type of switch used. The matrices analyzed the suction subsystem, filtration subsystem, electrical signal subsystem, and the overall system. Concept one received the highest score in each subsystem and in the overall system. Concept two received the second best scores in the overall system and subsystems, with the exception of electrical signaling. Concept three performed the worst, coming in last in all but one category. Concept one is chosen to be the basis for the final design concept and will be investigated further. See Appendix B for selection matrices.

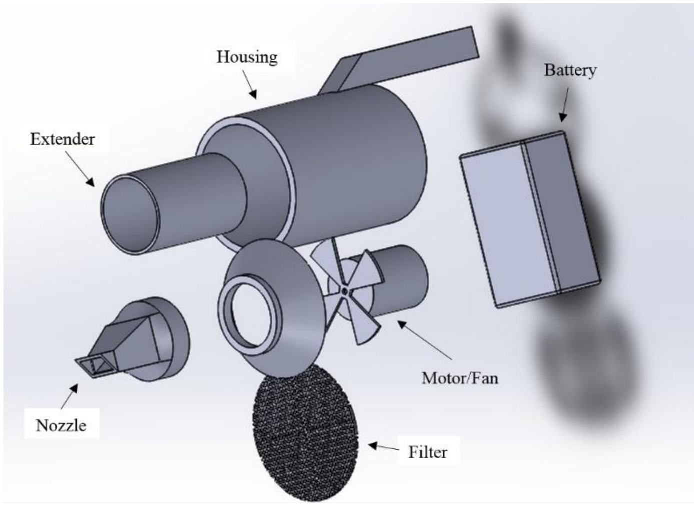
4. Detailed Design

4.1 Modifications to Proposal Sections

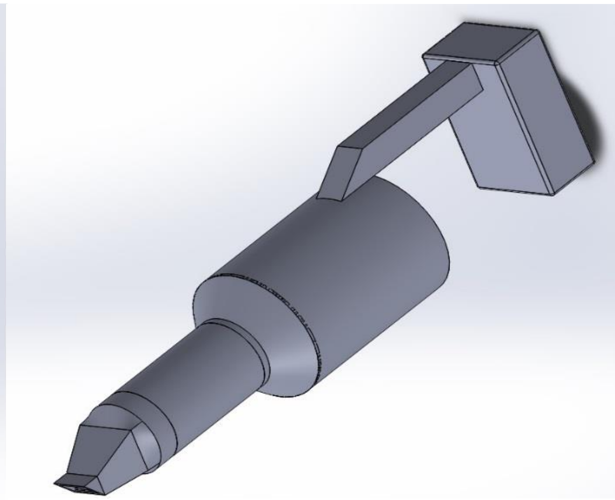
Since submitting the proposal, a few modifications have taken place in order to produce a working product. First, the design that was seen in the proposal was not meeting the requirements of the project statement. The battery was not in a position to be detachable or rechargeable. The final prototype features the battery mounted to the end of the handle to make it easier to detach and recharge. Another reason for the battery placement was to balance out the vacuum so it was not front-loaded with the housing, motor and nozzle. The housing was also slightly modified to create an easier way to empty the contents of the vacuum. A step down pipe was mounted in order to reduce weight and create a system where it is easier to empty the contents of the vacuum. Another reason for the step down was to reduce 3D printing costs. The nozzle is the only part that is 3D printed. The cost to make a nozzle to fit a 4" diameter pipe is much more expensive and it would go beyond the amount of 3D print allowed to the team. Instead the nozzle only had to fit a 2" diameter and used three cubic inches at a much more reasonable cost. The schedule had to be slightly modified, as the final prototype was finished 4 days after the scheduled date. Refer to the Gantt chart in Appendix A. As far as economic analysis, the 3D print job added more than the expected cost to produce. The theoretical analysis since the proposal had to be modified as well. In the introduction, the calculations use a 4" fan blade to calculate airflow and pressure difference. The fan that is implemented on the vacuum is a 3.5" axial fan. The fan costs about the same and is of the same material.

4.2 Overall Description

Exploded View



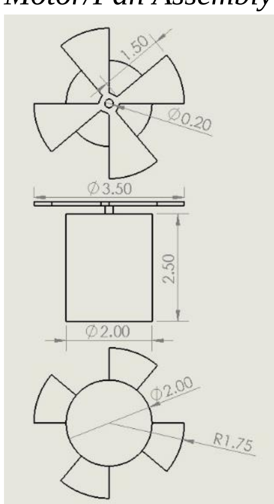
Assembled View



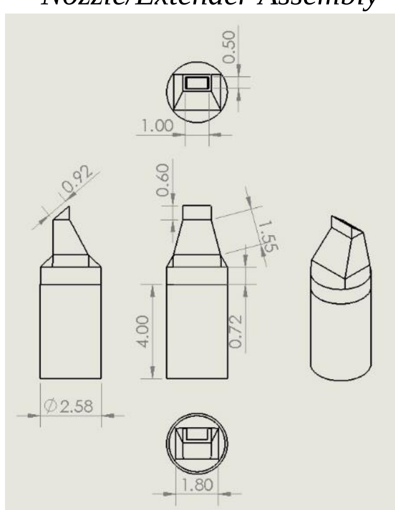
This vacuum is 20 inches long, 4.5 inches wide and 5 inches tall, weighing 10lbs. The final design utilizes a 3000 RPM motor 2 inches in diameter, and a 3.5" fan blade to create 1kPa of pressure and 55 CFM of air flow. The motor is powered by a 20 volt rechargable battery, which is detachable at the rear of the vacuum. There is a metal mesh filter in front of the fan to separate debris from clean air. The nozzle and body extender are detachable to empty the debris chamber. A cross-section view is in Appendix F.

4.3 Detailed Drawings

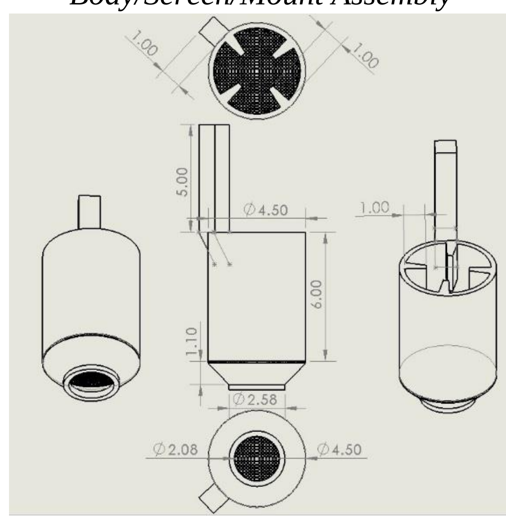
Motor/Fan Assembly



Nozzle/Extender Assembly



Body/Screen/Mount Assembly



See appendix F for individual component drawings. The motor will power a 3.5" fan blade. It is important to note the motor has a 2 inch diameter for mounting purposes. The nozzle has a .5" x 1.0" inlet. There is a channel that runs up the top of the nozzle to throw debris upward, increasing the capacity of the vacuum. The outer diameter of the extender is 2.5". The extender fits snugly into the body of the vacuum, and can be separated simply by pulling on it. The main body is one piece of 4.0" inner diameter plastic pipe and includes a step up in diameter, from the extender diameter of 2.5" to the body diameter of 4.0". The filter is a mesh vacuum bag. The filter is directly in front of the fan; the debris will collect in front of the filter and stay within the body. The motor mount consists of four arms that form a 2 inch circle, where the motor can be pressed into place. These arms allow air to flow around them without obstructing airflow. The battery is attached to the end of the handle using the same prong and latch system the drill used. All wiring and the switch are housed within the handle.

4.4 Final Theoretical Analysis

The System Curve and Fan Performance Curve were calculated to find the speed at which the vacuum's fan operated. The System Curve was found using the calculation for net head. The only unknowns in this equation were the two velocities and the pressure difference. Since the pressure difference was determined during testing and one velocity could be related to the other velocity from conservation of mass, only one unknown remained. By varying the unknown, velocity, and holding everything else constant, the System Curve was obtained. The Fan Performance Curve was obtained by using symmetry with the data of another similar fan. A set of data was found of an axial fan with a 120mm diameter operating at 4000 rpm. Using the pump affinity laws, the data was able to be related to the fan that was used in the vacuum and the Fan Performance Curve was obtained. The point at which the two lines intersected when put together on the same graph was almost identical to the calculated flow rate. The best efficiency point (BEP) was not able to be calculated because there was no data for torque that could be used in the calculation of W_{shaft}. Using the calculated volumetric flow rate and the known area of the nozzle, the velocity at the nozzle was able to be calculated. This velocity was determined to be 81.3 m/s. The velocity at the fan was calculated the same way using the area of the four inch diameter pipe; this was 0.79 m/s. Both of these values were then used in the head form of the energy equation to calculate the pressure drop at the inlet, which was 0.567 psi.

Final system performance curves and data can be found in Appendix I. Formulas Used:

$$H = \frac{P_1 - P_2}{\rho g} + \frac{\left(\frac{Q}{A_1}\right)^2 - \left(\frac{Q}{A_2}\right)^2}{2g} \qquad \frac{Q_1}{Q_2} = \frac{N_1}{N_2}\left(\frac{D_1}{D_2}\right)^2 \qquad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2\left(\frac{D_1}{D_2}\right)^2$$

4.5 Component and Material Selection Process

The majority of the vacuum housing will be made out of Acrylonitrile Butadiene Styrene. This is the best material to use for the housing because it is commonly used with injection molding. Injection molding would be the ideal process to create the housing because it enables pieces to be made with clips and fasteners already attached. Using the injection molding process also allows the housing for the motor to be connected directly to the outer housing, eliminating the setscrews that were used in the prototype. This makes for easy assembly and little human labor, which lowers the costs. The handle of the vacuum needs to be made out of something sturdy yet easy to grip; it also needs to be molded because it designed as an irregular shape made to fit a human hand comfortably. A moderately soft rubber, similar to a bicycle handgrip, seems to be the best option because it can be molded and prevents the operator's hand from slipping off the handle. Since this vacuum is being designed for ACME to go with a line of products that uses the same battery, the 18V battery that is used for the DrillMaster drill will be used for the vacuum as well. The motor that is used in the drill will also be recycled for use in the vacuum. The aluminum fan blade, mesh vacuum bag, and power switch can be ordered in bulk from a company such as

McMaster-Carr to reduce the cost of each item. Since the shaft from the motor is not the same size as the bore diameter of the fan blade, an aluminum step-up shaft will have to be made to mount the fan. The nozzle of the vacuum will be made out of the same Acrylonitrile Butadiene Styrene as the outer housing because it is durable and easy to mold.

Although making most of the vacuum out of plastic will cut the costs of production, it will have a rather large environmental impact. Since most old or broken vacuums are thrown in the trash, instead of being recycled, all of the plastic will be put into landfills. The plastic is not biodegradable so it hurts the environment. It could be replaced with recycled plastic but they are considerably more expensive. Using the same motor and battery as another product will positively impact the environment. Left over parts from the drill will be used on the vacuum, instead of getting rid of them to make room for a newer product.

4.6 Fabrication Processes for Mass Production

The housing and nozzle of the vacuum will be split into two halves and created using an injection press. The two molded halves will be attached together by a clip into place feature that is easy for assembly line workers to put together. Each half will have 2 runners to create a place for the motor to be clamped into place. See section 4.2 Overall Description to see the runners holding the motor into place. The motor will be placed inside the molding before the two halves are clamped together. Also, a 3.5” aluminum axial fan will be mounted to the motor’s shaft by way of press fit and tightened using a setscrew that comes with the fan. The injection mold will feature a slot for the mesh vacuum bag to slide into the slot. All these processes will be done on an assembly line before the two halves of the injection mold are clipped in together. The handle and battery attachment will be separate from the injection mold. A handle will be attached to the housing by another clip-in feature similar to the injection-molded halves. The handle will have a switch inserted on the front of the grip and a slot for the battery to clip in and out on the back of the grip. Assembly line laborers can also attach both of these features easily. Rechargeable battery packs and charging devices can be placed within the packaging of the vacuum but not attached to the vacuum since the switch may be in the ‘on’ position and run the battery dry.

4.7 Industrial Design

The vacuum is simple to use and easy to maintain. First, the switch is placed conveniently at the edge of the handle to make it easy for a thumb to be able to turn the vacuum on or off. The handle is placed at the center of mass of the vacuum. The battery sits at the end of one side of the handle while the other components are on the other. This includes the housing, fan, motor and nozzle. Since the handle is placed at the center of mass, the vacuum is comfortable to use and is easy to hold in one hand. The vacuum is safe to operate. The motor and spinning fan blade are enclosed within the housing so they are not out in the open for the user to touch but are still accessible to someone who knows how to use a screwdriver. The vacuum is sleek and smooth. The sleek appearance of the vacuum reflects how powerful the vacuum really is. It is simple in design yet effective in its purpose.

4.8 Economic Analysis

4.8.1 Unit Production Cost

The housing and handle are Acrylonitrile Butadiene Styrene injected molding based on custompart.net cost estimator tool. Direct costs are based on fixed and variable costs to do with the cost of an injection-molding machine, maintenance of machinery and power consumption. These values are estimated from Pit Falls in Molding[14]. Overhead charges and assembly costs are estimates from the textbook Product Design and Development. Overhead is 10% of material costs and 80% of all labor costs, according to the textbook. Also, assembly time according to the book takes between 4 and 60 seconds for basic assemblies. The hourly wages for assembly labor is unskilled and set at $1.82 per hour. Processing and tooling for the injection molding machines is considered skilled labor and is set at $15.14 per hour. Complete Bill of Materials can be found in Appendix G.

4.8.2 Business Case Justification

These numbers are estimated from Polaroid's development of a new camera, assuming the vacuum company will take about half the cost to develop and run production. The first four quarters will be spent in developing the product, with a total cost of $2 million in development. Ramp up will occur during quarters 4 and 5 to create the infrastructure to support production, at a total cost of $1. Marketing and support costs throughout production remain steady at $400,000 per year. The production rate is 100,000 units per year, or 25,000 units per quarter. Including parts, materials, tooling, labor, and overhead, each unit costs $24.66, amounting to $616,500 per quarter. At a 100% markup, the selling price of the vacuum is $50. Assuming all units produced are sold within that quarter, sales revenue is %1.25 million per quarter. With an annualized discount rate of 10%, the net present value of the company after 4 years is $1.45 million. Final NPV chart can be found in Appendix H.

4.9 Safety

The Rice Buster follows safety regulations set by IEC, the International Electrical Commission, which oversees international consumer product safety. The common portable vacuum falls under common household appliances. The IEC limits the amount of information they give out for the free preview. However, there is enough there to conclude that the Rice Buster meets international safety standards. First, it requires vacuum cleaners to have a voltage less than 250 Volts. The Rice Buster includes a 20 V, which exceeds this requirement. IEC says it has to be safe around persons whose "physical, sensory or mental capabilities; or lack of experience of knowledge prevents them from using the appliance safely without supervision or instruction." [15] The Rice Buster has a switch that is accessible when the vacuum handle is gripped correctly. If someone had a lack of mental capability, they would not be able to turn this on easily since the vacuum must be gripped correctly in order to have access to the switch. Besides it being hard to turn on, the vacuum is not dangerous when turned on. The small inlet of the vacuum's nozzle creates it hard for larger objects to be accidently picked up by the vacuum. The IEC also mentions the vacuum cannot be harmful to children playing with the product. The smooth design of the Rice Buster will not be harmful since nothing is poking out or potentially harmful to bump into. Also, the Rice Buster does not feature any small objects that could potentially be swallowed by infants or small children.

4.10 Prototype Construction Process

See appendix J for pictures of the prototype and its components. The body is made of PVC tubing cut to size. The motor is stripped of all gears. The shaft of the motor is attached to the shaft of the fan using an aluminum connecting piece, fabricated with a lathe, and press fit into place. The fan is metal, purchased from McMaster-Carr. The motor is mounted inside the body of the vacuum using six set screws tightened down from different angles to secure the motor. The handle is bolted to the body internally using two bolts. The switch is press fit into the handle, and all the wiring, from the battery, to the switch, to the motor, and back to the battery, is run through the handle. Attached to the handle is the original battery mount of the drill, to which the battery is attached. The filter is made of a metal mesh screen, which is glued onto the body. The nozzle is 3D printed, and is attached to the extender with a press fit.

5. Testing

5.1 Test Procedure and Plan

The purpose of the prototype is to demonstrate how the vacuum will work and confirm that it is simple to use by an everyday customer. The prototype created reflects how the manufactured product will work. There were multiple tests done to test the vacuum's ability to create effective suction. The first test is to see how much rice the vacuum could suck up in a 20 second time period and be able to empty the contents into a bin or bucket. About 3 pounds of uncooked grained rice is spread onto a flat surface. Next, turn the vacuum on and pick up as much rice in 20 seconds. After that, empty the debris into a bucket to be measured on a scale. The next test is similar except that there is no time limit. This test is to see how much uncooked rice the vacuum is able to hold. The third test is again similar except it is to see how much rice can be vacuumed in a 5 second period. All three tests use the same set up by pouring 3 pounds of uncooked rice onto a table or flat surface. The last two tests are different in that it does not involve rice. The first test is to test flow rate and is done with a flow meter. A plastic tube must be attached to the vacuum so that the diameter of the inlet fits the size of the flow meter. The vacuum is turned on when the inlet of the vacuum, plastic tube, is flush with the flow meter. Wait for the flow meter to settle on a value and record the data. Repeat to create a more accurate distribution of data. The last test is finding pressure difference created by the fan and is done with the help of a manometer. One tube of the manometer should be attached to a rubber stopper that is plugged into the plastic tube used for the flow rate test. The other pipe coming out of the manometer should be let free so that it can measure the pressure difference with respect to atmospheric pressure. When set up, turn the vacuum on, let the manometer settle to a value and record. Again, repeat to get more accurate data. Each test was completed once on the prototype-testing day. The vacuum was able to pick up and hold 0.932 pounds in 20 seconds. Next, the maximum capacity test showed that it could hold 1.032 pounds. Then, the flow rate test show that it could pick up 0.518 pounds in 5 seconds, which scaled to 0.1036 pounds per second. The non-rice affiliated flow rate test yielded a rate of 11.45 meters per second. Lastly, the manometer tested a pressure difference of 0.9 kPa. To get more accurate data it would be wise to repeat the stated tests and get an average of these values.

5.2 Test Results and Discussion

The predicted performance of the vacuum was much higher than the test results that were obtained after the competition. The pressure drop at the inlet was predicted to be 0.567 psi (3.9 kPa) and the measured pressure drop was 0.9 kPa. This could be due to the fact that under an applied load, the motor did not have enough power to keep the span spinning at its optimum speed. It could also be because the vacuum was not completely airtight and there was a slight gap between the fan and the inside of the vacuum chamber for air to slip through. The velocity at the inlet was predicted to be 81.3 m/s, but the measured velocity was only 11.45 m/s. This large difference was definitely affected by the gap between the fan and the interior wall and all the obstructions of airflow inside of the vacuum. The angled inlet, filter, and sharp corners where pieces connected would have caused eddies in the flow that would obstruct its path. Even though both the velocity and pressure were predicted to be much higher, the vacuum was still able to pick up a large amount of rice. A grain of rice weighs only a fraction of an ounce, so the 0.9 kPa (0.15 psi) pressure drop created enough suction to pick it up. The amount of rice that could be picked up was only affected by the size of the collection chamber. Once it became filled, it blocked off the inlet completely.

6. Conclusion

The Rice Buster is a cordless handheld vacuum to be used in a car, dorm room, stairwell, or small area. According to a customer survey, the target customer wants a portable, powerful, and affordable vacuum cleaner. These customer needs were used to distinguish between prototypes and choose a final design. The final design meets all identified customer needs. Its compact design makes it lightweight and easy to handle, and a three and a half inch diameter fan creates strong suction. The Rice Buster's cordless design allows the user to clean in areas without an outlet nearby. The Rice Buster targets several audiences creating a large potential market. College students can use The Rice Buster in their dorm room for small jobs in tight spaces. The elderly can use the lightweight design for hard to reach areas or small jobs that do not require a full size vacuum. Anyone who owns a vehicle can easily clean their car without the hassle of a cord. The Rice Buster allows the user to clean anywhere without the restriction of being near a power outlet. The manufacturing cost of the Rice Buster is $24.66 per unit. Market research shows that handheld cordless vacuum cleaners range in price from $47.00 to over $150.00. With a markup of 100%, The Rice Buster will be sold for an affordable price of $50, which is extremely competitive in the marketplace. Taking all costs into account, the net present value of the company is $1.45 million after 4 years, netting $500,000 in profit per quarter for as long as production continues. This economical, lightweight, and functional vacuum cleaner appeals to a large potential market, and is priced so that it is affordable to any customer looking to buy a new vacuum cleaner.

7. References

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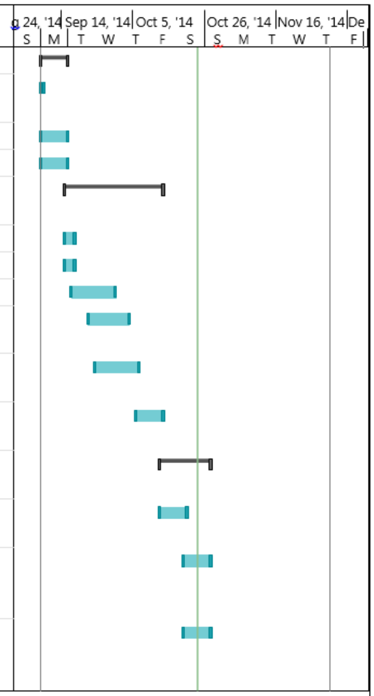
8. Appendices

Appendix A

Gantt Chart

ID	Task Name	Duration	Start	Finish	Responsibility
1	**Planning**	**6 days**	**Mon 9/8/14**	**Mon 9/15/14**	
2	Receive Project Statement	1 day	Mon 9/8/14	Mon 9/8/14	All
3	Team Contract	6 days	Mon 9/8/14	Mon 9/15/14	All
4	Pick-up Drill	6 days	Mon 9/8/14	Mon 9/15/14	Jason/Kevin
5	**Concept Development**	**21 days**	**Mon 9/15/14**	**Mon 10/13/14**	
6	Benchmarking	3 days	Mon 9/15/14	Wed 9/17/14	Kevin
7	Patent Search	3 days	Mon 9/15/14	Wed 9/17/14	Ryan
8	Drill Tests	9 days	Wed 9/17/14	Mon 9/29/14	Jason/Kevin
9	Facebook Survey	10 days	Mon 9/22/14	Fri 10/3/14	Ryan
10	Generate Concepts	9 days	Wed 9/24/14	Mon 10/6/14	All
11	Concept Selection	6 days	Mon 10/6/14	Mon 10/13/14	All
12	**System-level Design**	**11 days**	**Mon 10/13/14**	**Mon 10/27/14**	
13	Overall Description	6 days	Mon 10/13/14	Mon 10/20/14	Ryan
14	Preliminary Theoretical Analysis	6 days	Mon 10/20/14	Mon 10/27/14	Jason
15	Preliminary Economic Analysis	6 days	Mon 10/20/14	Mon 10/27/14	Kevin

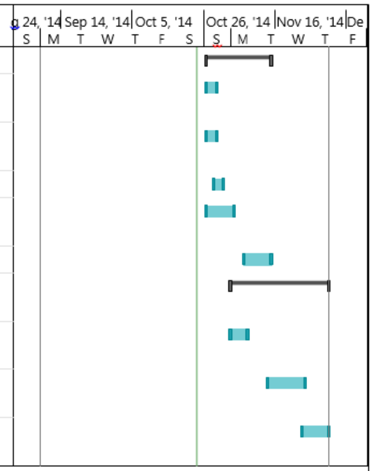


Project: Rice Buster
Date: Mon 10/27/14

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
Milestone	Duration-only	Deadline
Summary Project	Manual Summary Rollup	Progress Manual
Summary	Manual Summary	Progress
Inactive Task	Start-only	
Inactive Milestone	Finish-only	

Page 1

ID	Task Name	Duration	Start	Finish	Responsibility
16	**Detail Design**	**15 days**	**Mon 10/27/14**	**Fri 11/14/14**	
17	Overall Description	3 days	Mon 10/27/14	Wed 10/29/14	Ryan
18	Detailed Drawings	3 days	Mon 10/27/14	Wed 10/29/14	Jason
19	Final Analysis	3 days	Wed 10/29/14	Fri 10/31/14	All
20	Alpha Prototype	6 days	Mon 10/27/14	Mon 11/3/14	All
21	Beta Prototype	6 days	Fri 11/7/14	Fri 11/14/14	All
22	**Testing and Refinement**	**21 days**	**Mon 11/3/14**	**Mon 12/1/14**	
23	Test Alpha Prototype	5 days	Mon 11/3/14	Fri 11/7/14	All
24	Test Beta Prototype	7 days	Fri 11/14/14	Mon 11/24/14	All
25	Final Product	6 days	Mon 11/24/14	Mon 12/1/14	All



Project: Rice Buster
Date: Mon 10/27/14

Task
Split
Milestone
Summary Project
Summary
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
External Tasks
External Milestone
Deadline
Progress Manual
Progress

Appendix B

Concept Selection

Subsystem 1: Suction							
		Concept 1		**Concept 2**		**Concept 3**	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Power	5	4	20	2	10	3	15
Weight	3	2	6	4	12	3	9
Size	3	3	9	5	15	1	3
Filter Quality	3	4	12	4	12	2	6
Aesthetics	2	0	0	0	0	0	0
Ergonomics	2	0	0	0	0	0	0
Collection Chamber	4	3	12	2	8	2	8
Switch Method	3	0	0	0	0	0	0
	Total Score		59		57		41
	Rank	**1**		**2**		**3**	
Subsystem 2: Air Filtration							
		Concept 1		**Concept 2**		**Concept 3**	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Power	5	4	20	2	10	3	15
Weight	3	4	12	4	12	2	6
Size	3	3	9	3	9	4	12
Filter Quality	3	4	12	4	12	1	3
Aesthetics	2	0	0	0	0	0	0
Ergonomics	2	0	0	0	0	0	0
Collection Chamber	4	3	12	3	12	4	16
Switch Method	3	0	0	0	0	0	0

	Total Score		65		55		52
	Rank	**1**		**2**		**3**	

Subsystem 3: Electrical Signal

		Concept 1		**Concept 2**		**Concept 3**	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Power	5	0	0	0	0	0	0
Weight	3	5	15	5	15	5	15
Size	3	3	9	4	12	2	6
Filter Quality	3	0	0	0	0	0	0
Aesthetics	2	4	8	4	8	4	8
Ergonomics	2	3	6	2	4	4	8
Collection Chamber	4	0	0	0	0	0	0
Switch Method	3	3	9	2	6	3	9
	Total Score		47		45		46
	Rank	**1**		**2**		**3**	

Overall Configuration

		Concept 1		**Concept 2**		**Concept 3**	
Selection Criteria	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Power	5	5	25	3	15	4	20
Weight	3	4	12	5	15	2	6
Size	3	3	9	5	15	2	6
Filter Quality	3	4	12	4	12	3	9
Aesthetics	2	3	6	4	8	3	6
Ergonomics	2	4	8	4	8	3	6
Collection Chamber	4	3	12	3	12	4	16
Switch Method	3	4	12	3	9	4	12
	Total Score		96		94		81
	Rank	**1**		**2**		**3**	

Appendix C

<u>QFD Chart</u>

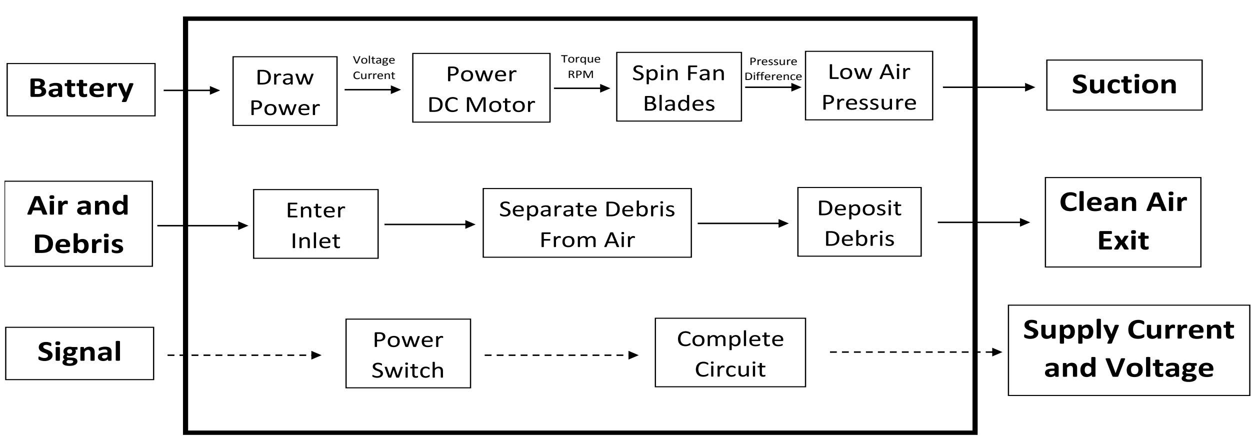
	Need \ Metric	1 Power (watts)	2 Weight (lbs)	3 Size (ft^3)	4 Filter Quality (% reduction of area)	5 Aesthetics (type of material)	6 Ergonomics (level of comfort)	7 Collection Chamber (ft^3)	8 Switch Method (level of comfort)
1	Long Battery Life	•			•				•
2	Good Suction	•			•			•	
3	Durable			•					•
4	Lightweight		•			•			
5	Easy to Empty						•	•	

Appendix D

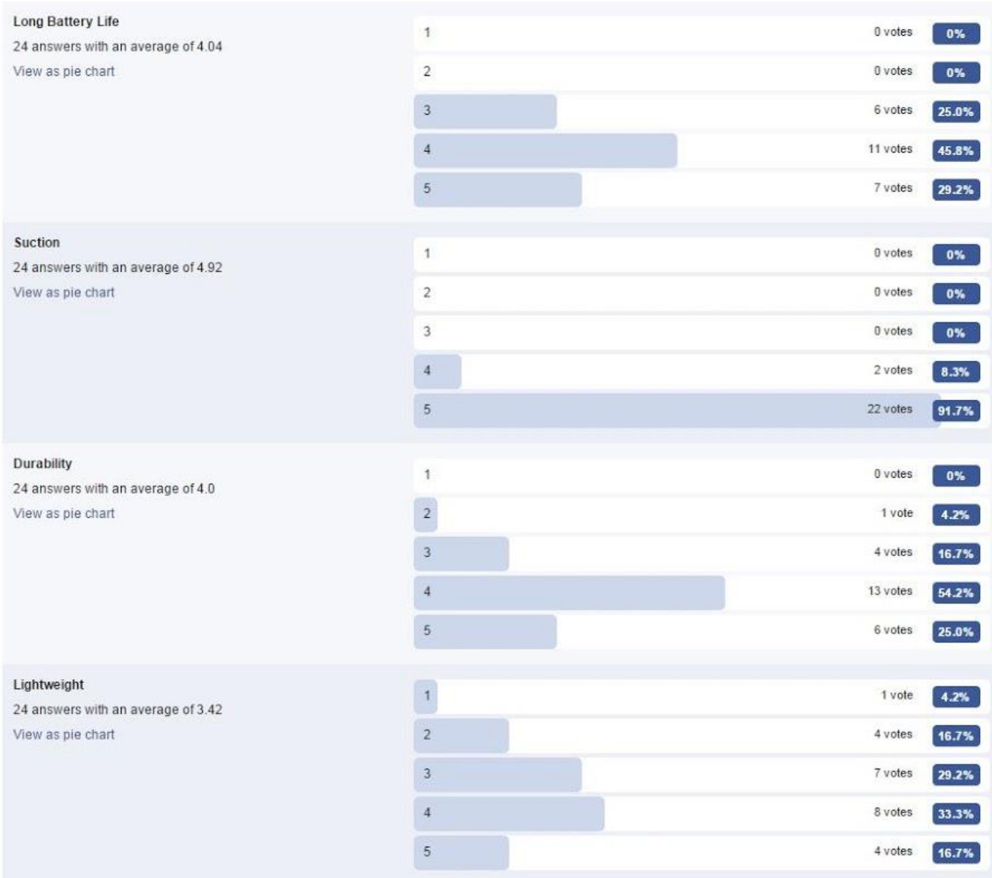
Benchmarking

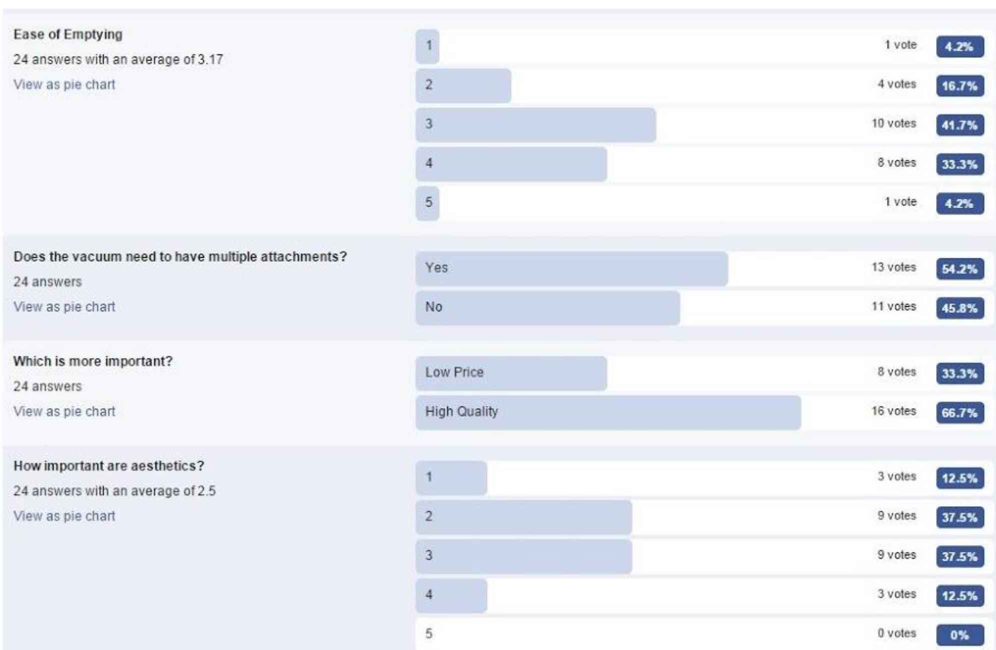
Metric No.	Need No	Metric	Importance (1-5)	Units	Shark[6] V1510	Black&Decker[6] BDH2000FL	Dirt Devil[5] BD10175	Dyson[4] DC34	Hoover[7] BH50030
1	1,2	Power	4	Volts	120.0	20.0	18.0	22.2	18.0
2	4	Weight	3	lbs	7.2	3.8	3.9	2.9	6.2
3	3	Size	3	ft^3	0.645	0.541	0.260	0.262	0.354
4	1,2	Filter Quality (bagless)	4	y/n	yes	yes	no	yes	yes
5	4	Aesthetics (1-5)	2	rank (1=best)	1	4	5	1	2
6	5	Ergonomics	2	n/a	-	-	-	-	-
7	2,5	Collection Chamber size	4	Volume	-	-	-	-	-
8	1,3	Switch Method	3	n/a	handle switch	side button	handle switch	trigger	handle switch
	1	Battery Life	3	minutes	cord	20	5	15	10
	3	Durability	2	Warranty Years	3	3	3	5	2
		Price	4	US Dollars	$44.22	$129.00	$46.90	$149.99	$118.99

Black Box



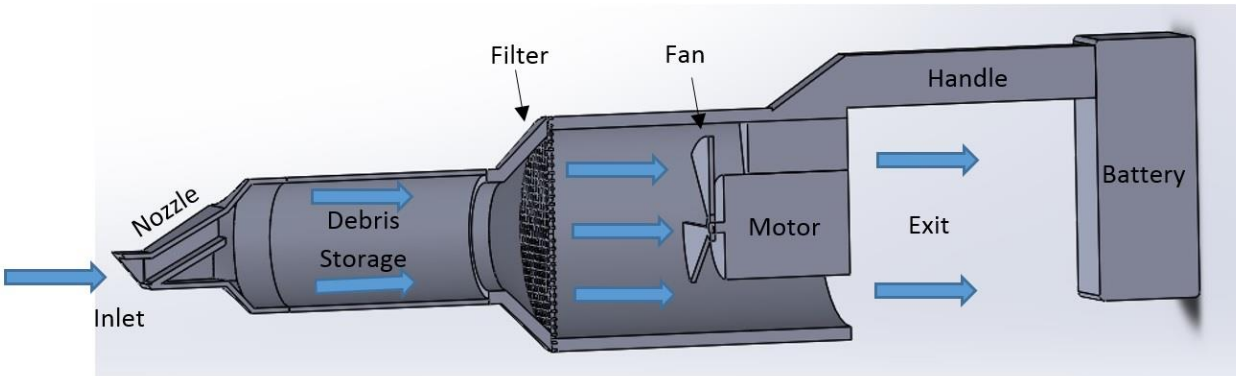
Appendix E

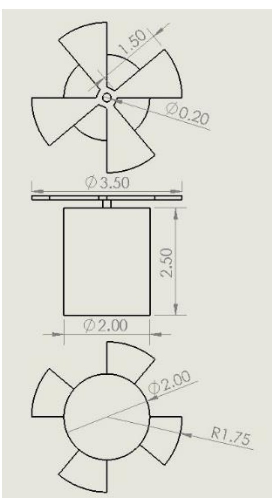

Long Battery Life
24 answers with an average of 4.04
View as pie chart
1
0 votes
0%
2
0 votes
0%
3
6 votes
25.0%
4
11 votes
45.8%
5
7 votes
29.2%
Suction
24 answers with an average of 4.92
View as pie chart
1
0 votes
0%
2
0 votes
0%
3
0 votes
0%
4
2 votes
8.3%
5
22 votes
91.7%
Durability
24 answers with an average of 4.0
View as pie chart
1
0 votes
0%
2
1 vote
4.2%
3
4 votes
16.7%
4
13 votes
54.2%
5
6 votes
25.0%
Lightweight
24 answers with an average of 3.42
View as pie chart
1
1 vote
4.2%
2
4 votes
16.7%
3
7 votes
29.2%
4
8 votes
33.3%
5
4 votes
16.7%

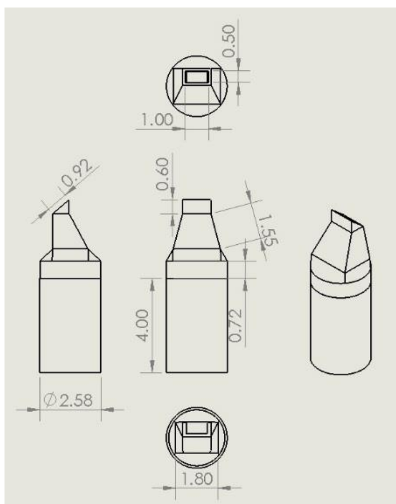

Ease of Emptying
24 answers with an average of 3.17
View as pie chart
1
1 vote
4.2%
2
4 votes
16.7%
3
10 votes
41.7%
4
8 votes
33.3%
5
1 vote
4.2%
Does the vacuum need to have multiple attachments?
24 answers
View as pie chart
Yes
13 votes
54.2%
No
11 votes
45.8%
Which is more important?
24 answers
View as pie chart
Low Price
8 votes
33.3%
High Quality
16 votes
66.7%
How important are aesthetics?
24 answers with an average of 2.5
View as pie chart
1
3 votes
12.5%
2
9 votes
37.5%
3
9 votes
37.5%
4
3 votes
12.5%
5
0 votes
0%

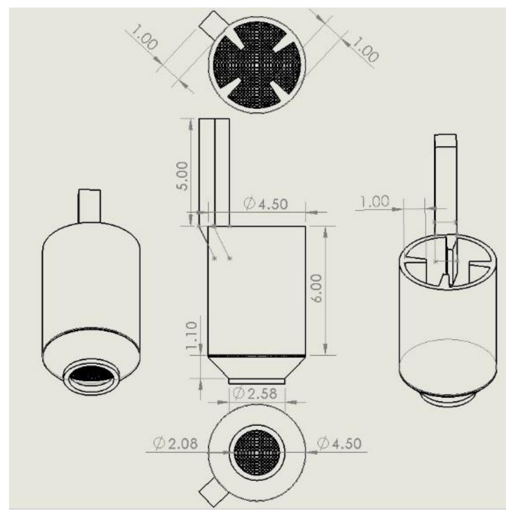
Appendix F

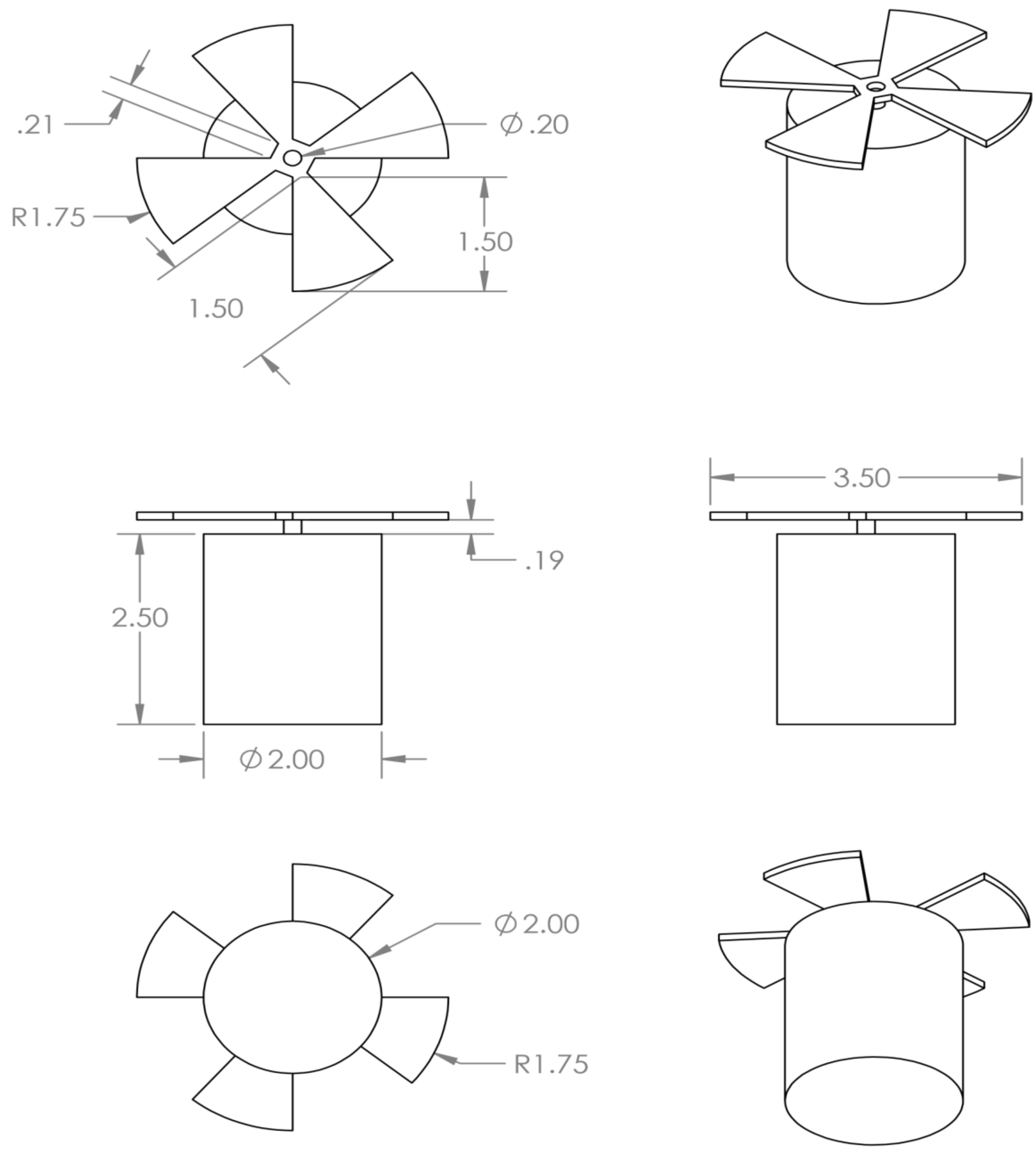
Detailed Drawings











PROPRIETARY AND CONFIDENTIAL

NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE	DWG. NO.	REV.
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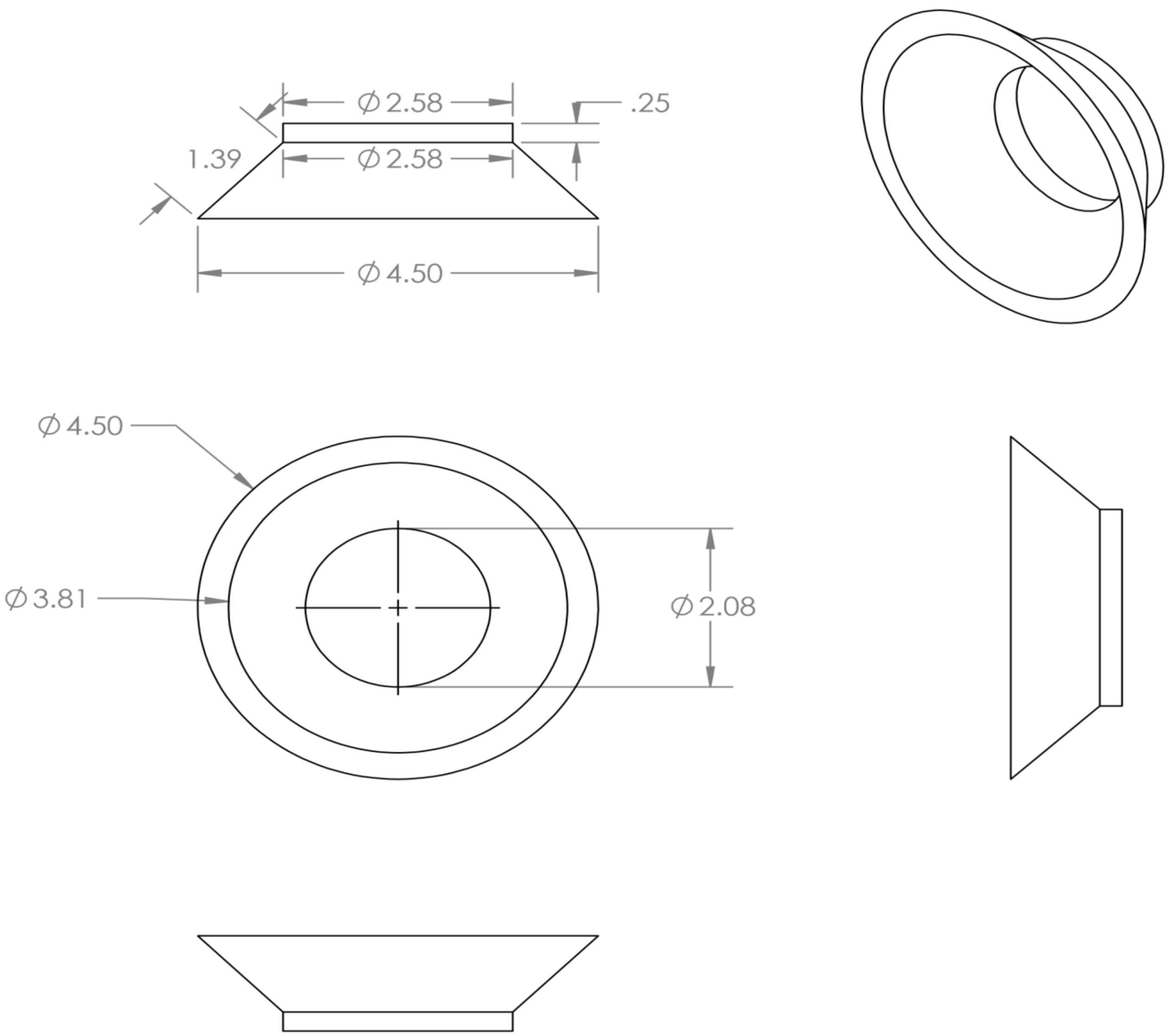
SCALE:1:2	WEIGHT:	SHEET 1 OF 1



		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±		NAME	DATE
			DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		MATERIAL	Q.A.		
		FINISH	COMMENTS:		
NEXT ASSY	USED ON				
APPLICATION		DO NOT SCALE DRAWING			

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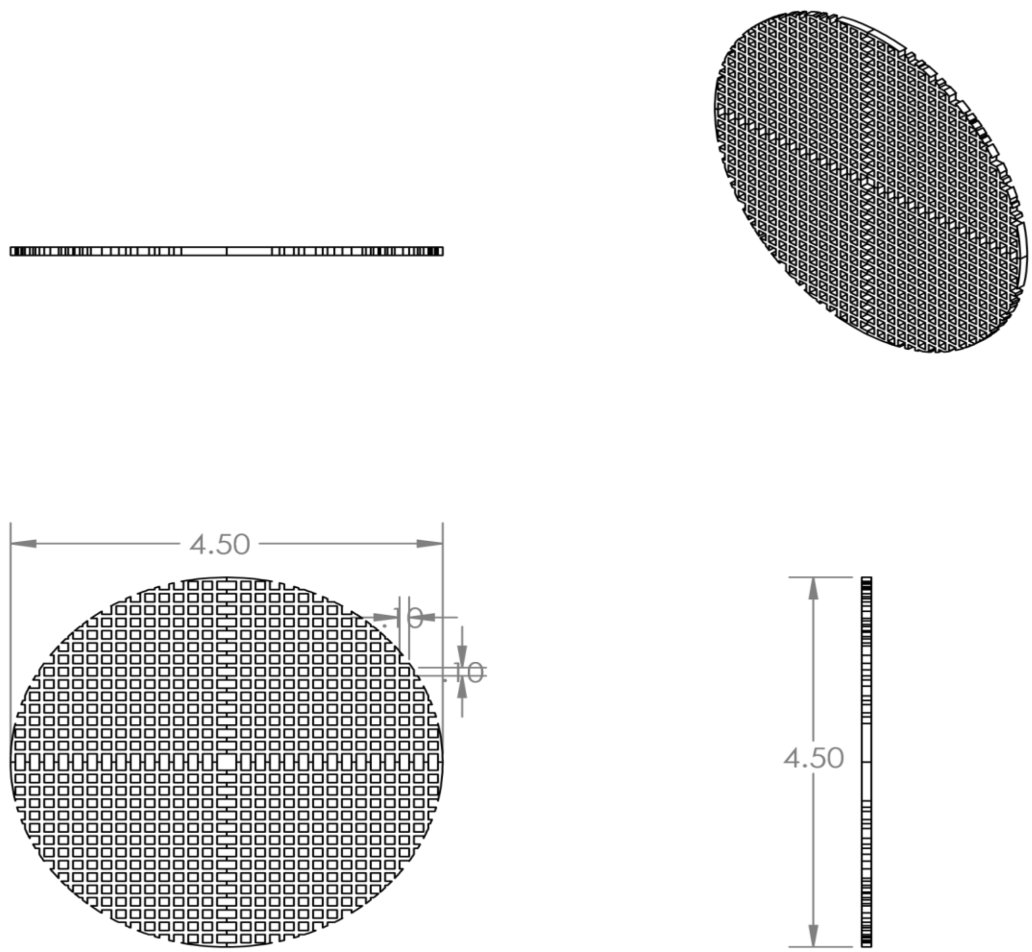
SCALE:1:2	WEIGHT:	SHEET 1 OF 1



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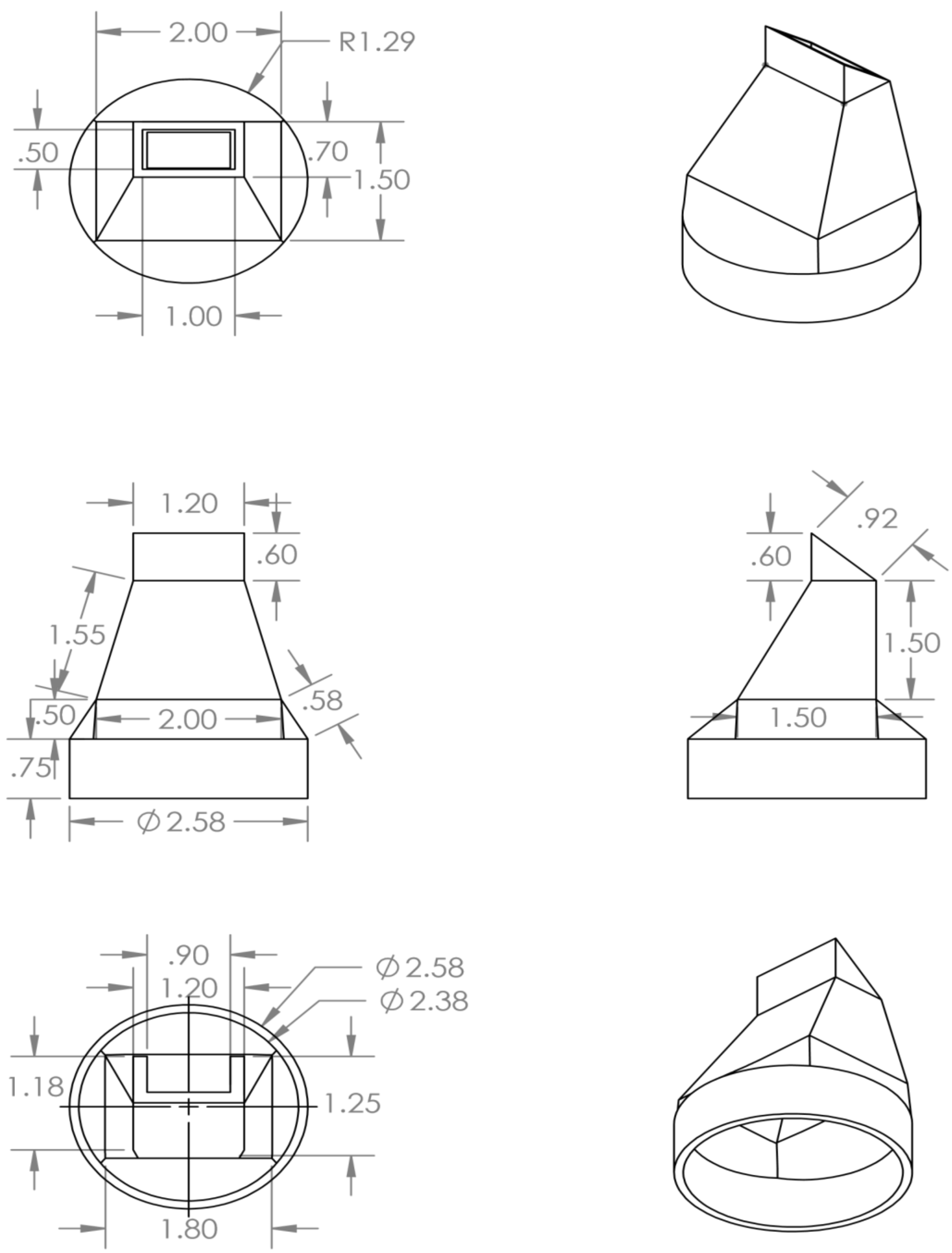
			DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		MATERIAL	Q.A.		
		FINISH	COMMENTS:		
NEXT ASSY	USED ON				
APPLICATION		DO NOT SCALE DRAWING			

SIZE	DWG. NO.	REV.
A	ScreenAssembly	
SCALE:1:2	WEIGHT:	SHEET 1 OF 1



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NEXT ASSY | USED ON

APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

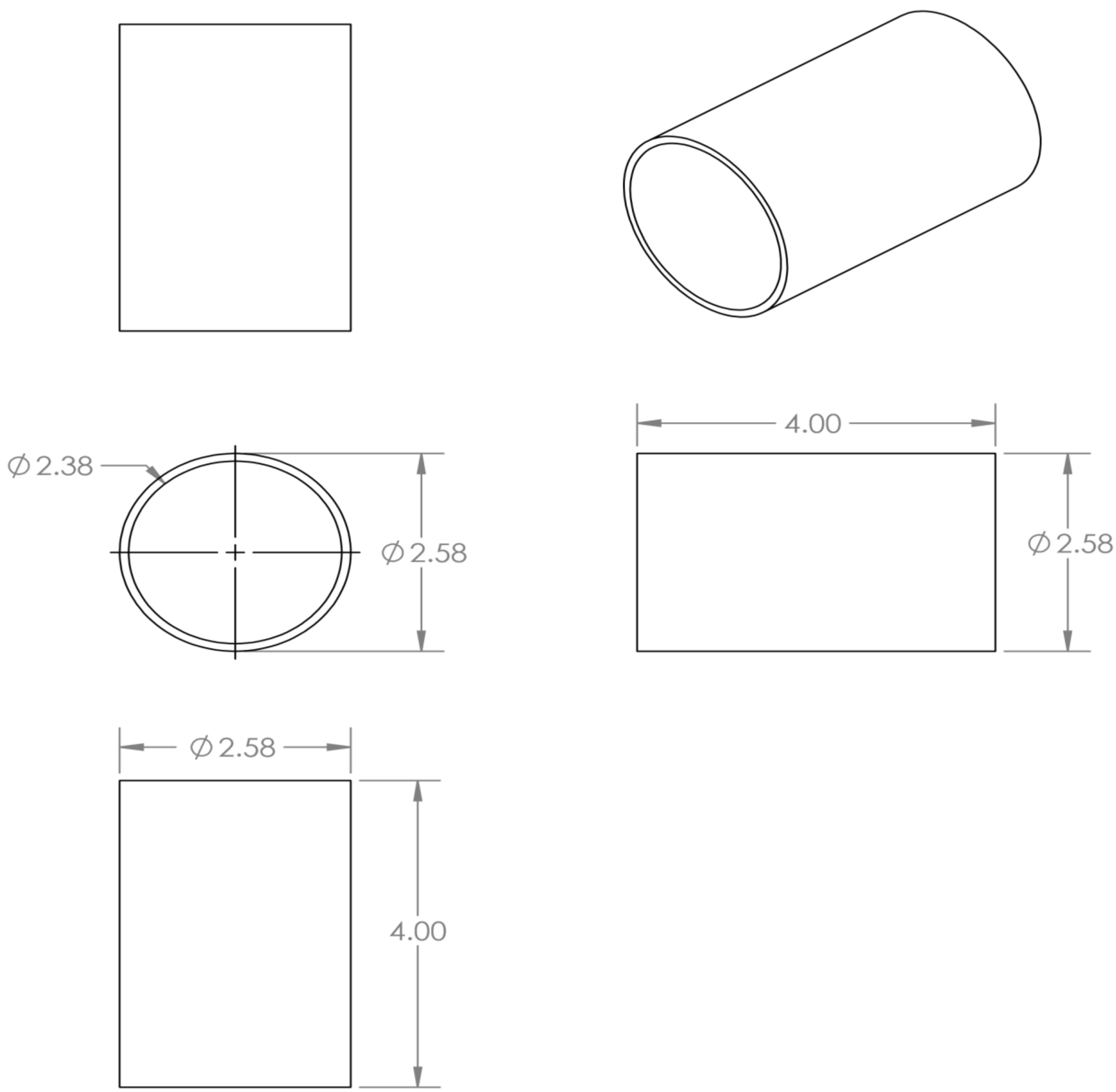
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE A | DWG. NO. FINALFINALNOZZLE | REV.

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

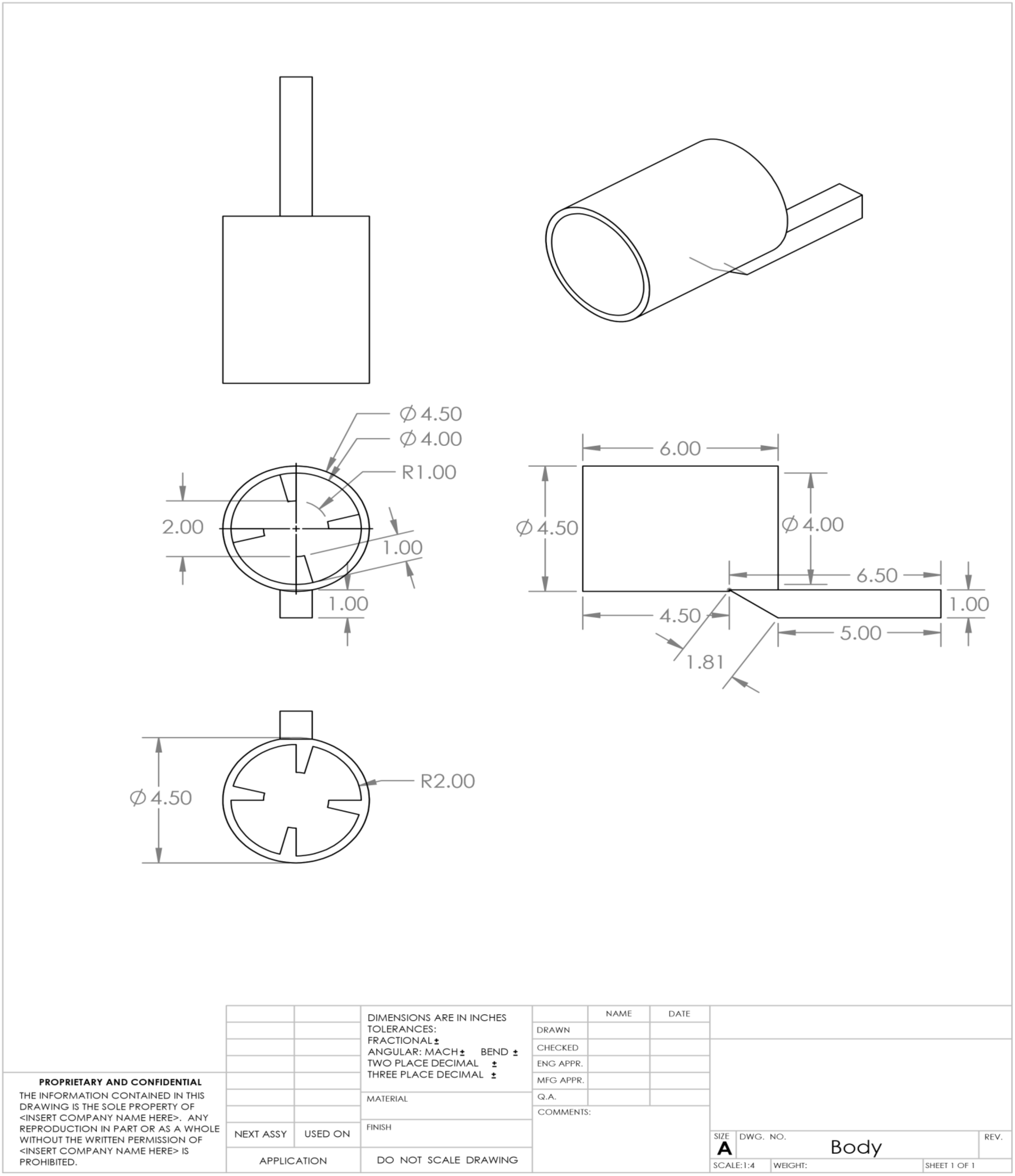
DO NOT SCALE DRAWING

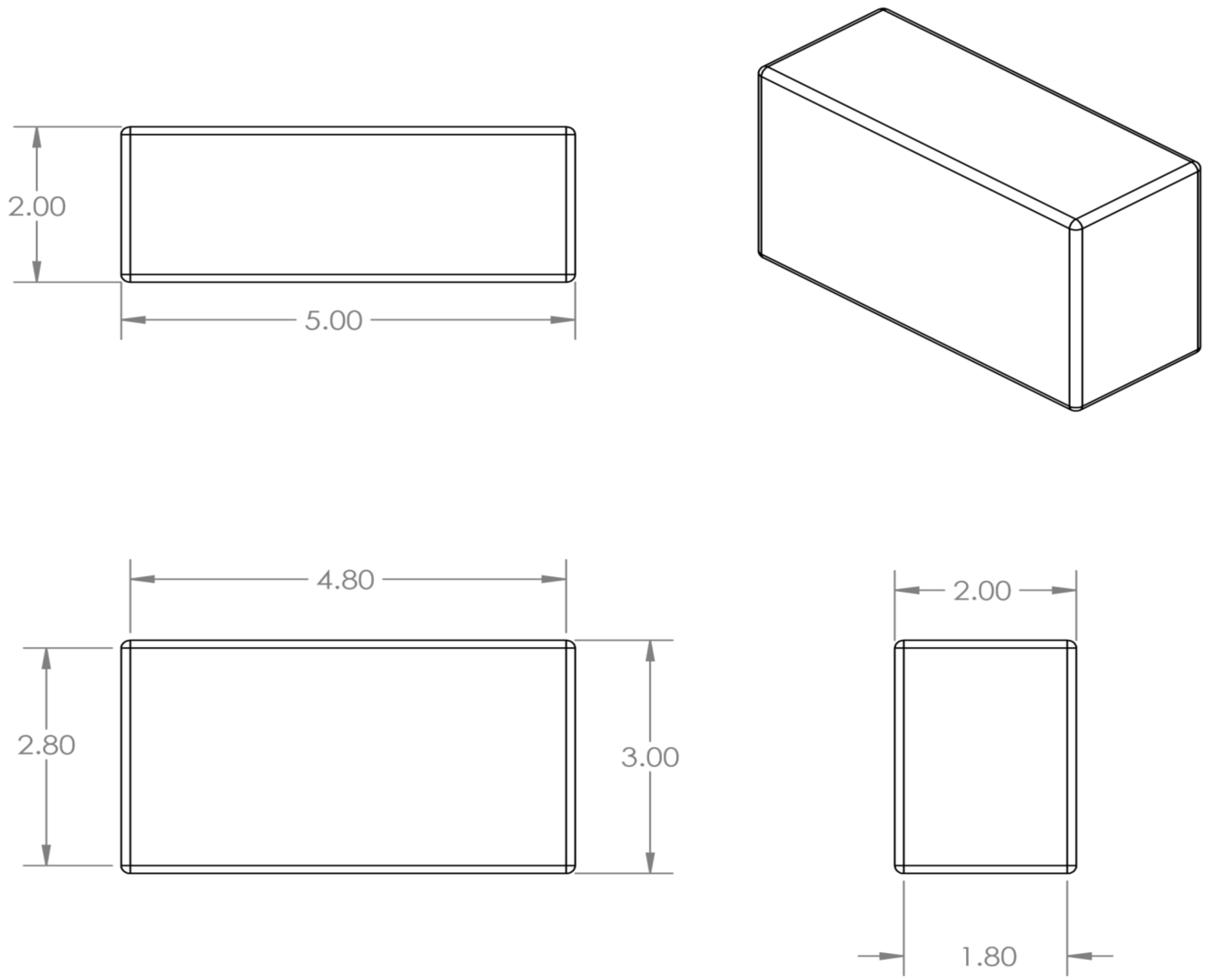
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE	DWG. NO.	REV.
A	Extender	

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1


Ø 4.50
Ø 4.00
R1.00
2.00
1.00
1.00
6.00
Ø 4.50
Ø 4.00
6.50
1.00
4.50
1.81
5.00
Ø 4.50
R2.00
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NEXT ASSY
USED ON
APPLICATION
MATERIAL
FINISH
DO NOT SCALE DRAWING
SIZE
A
DWG. NO.
Body
REV.
SCALE:1:4
WEIGHT:
SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY | USED ON

APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

SIZE A | DWG. NO. battery | REV.

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1

Appendix G

Bill of Materials

Component	**Purchased Materials**	**Processing**	**Assembly**	**Tooling**	**Total Cost**
Housing[12]	6.635	0.09	0.015	0.212	6.952
Handle[12]	1.206	0.044	0.015	0.133	1.398
Motor[9] Alibaba Model No. YJ58-16	1.25	0	0.015	0	1.265
Fan[13] McMastercarr Model No. 17545K63	2.52	0	0.015	0	2.535
Battery[8] Alibaba Model No. SC1300	5	0	0	0	5
Switch[10] Alibaba Model No. HCKD-044	0.1	0	0.015	0	0.115
Mesh Bag[11] Alibaba Model No. WZ-021	0.5	0	0.015	0	0.515
Total Direct Costs	3.9205	0.7841	0	0	4.7046
Overhead Charges	1.7211	0.1072	0.072	0.276	2.1763
Total Cost Per Unit					**24.66**
Annual Costs (100,000 units)					**2,466,000.00**

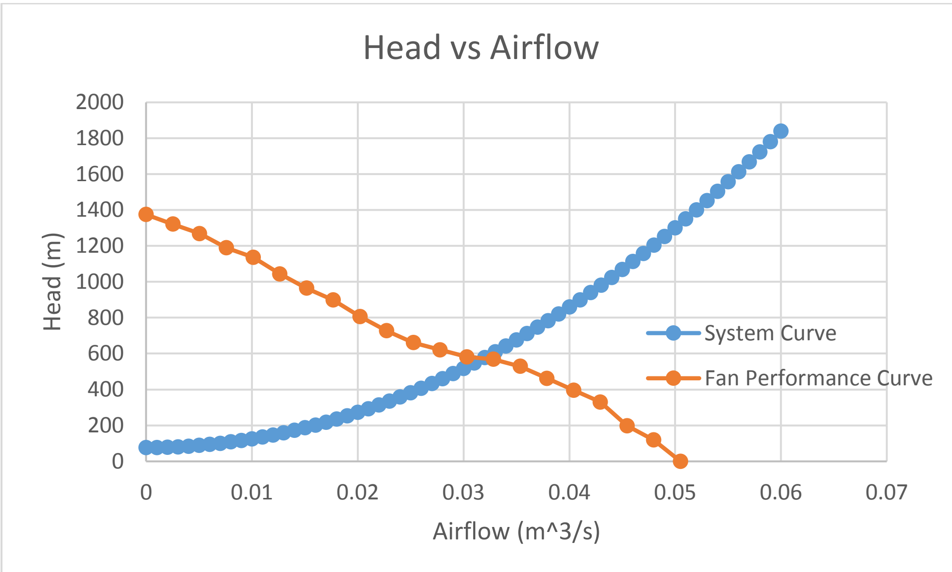
Appendix H

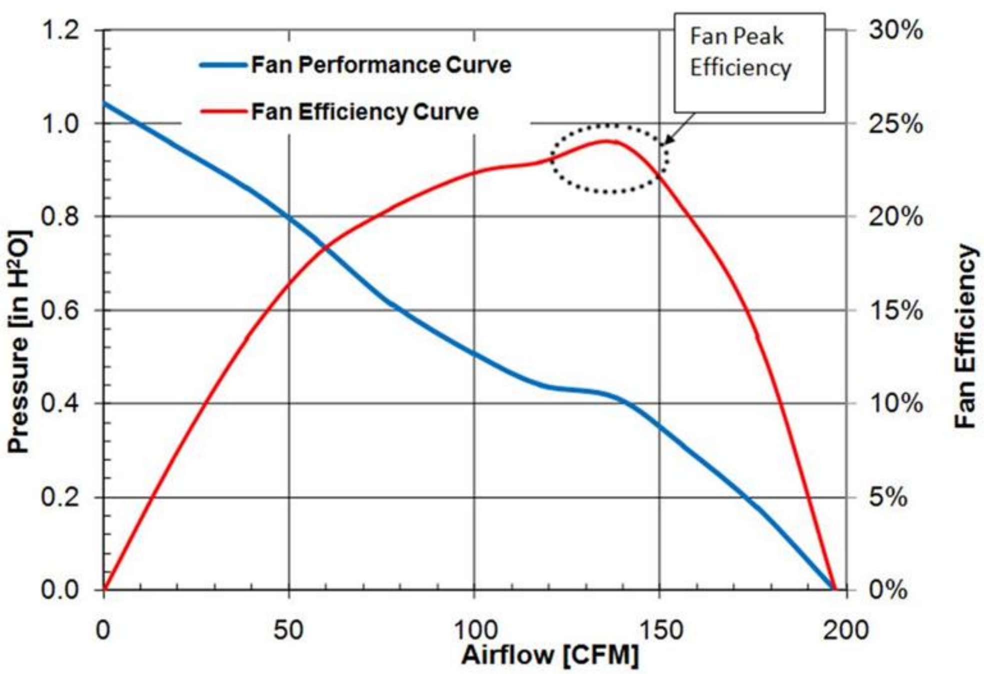
NPV Chart

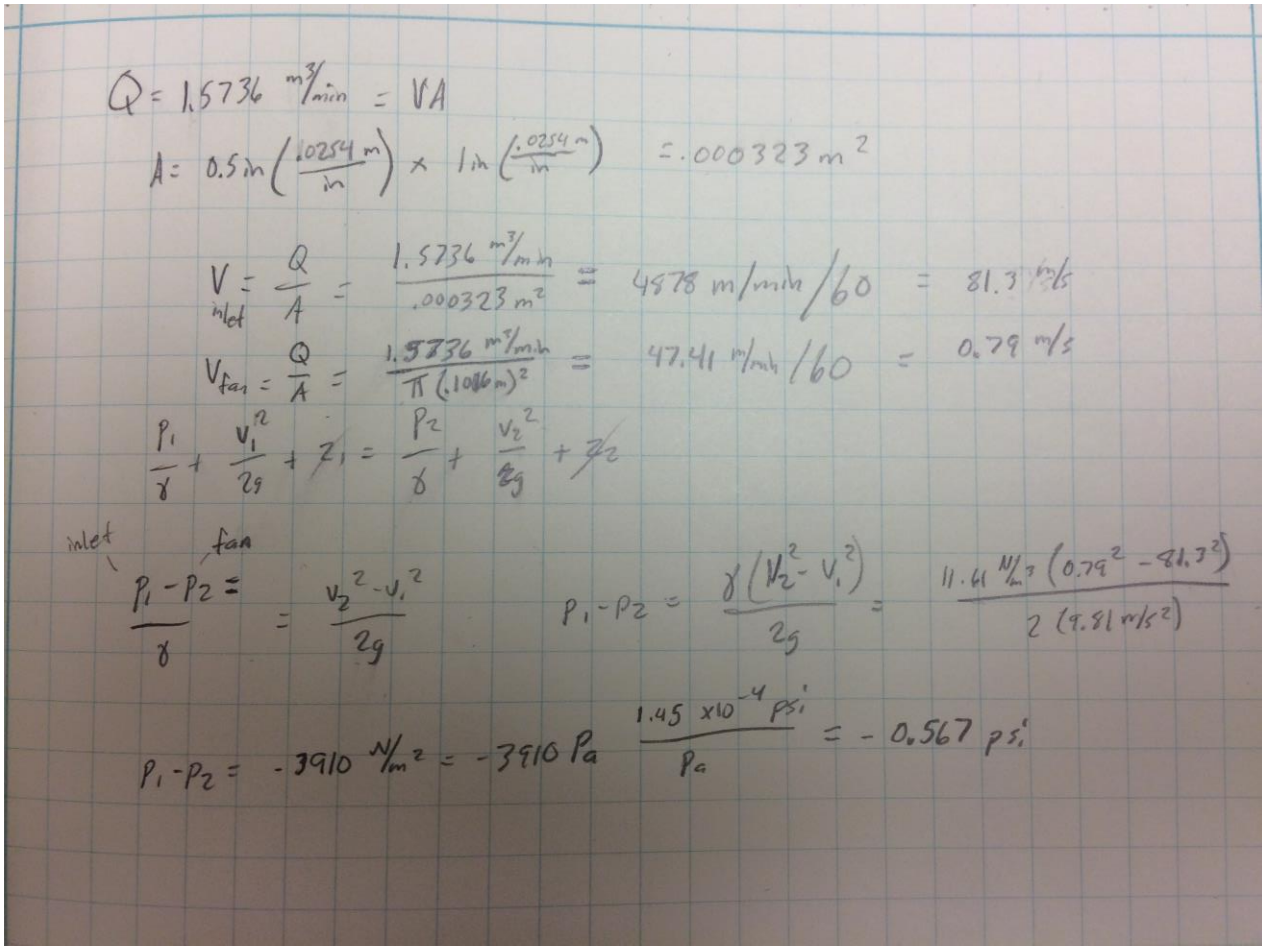
	Year 1				Year 2				Year 3				Year 4			
($ Values in Thousands)	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Development Cost	-500	-500	-500	-500												
Ramp-up Cost				-500	-500											
Marketing & Support Cost					-125	-125	-125	-125	-125	-125	-125	-125	-125	-125	-125	-125
Production Cost						-617	-617	-617	-617	-617	-617	-617	-617	-617	-617	-617
Production Volume						25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Unit Production Cost						.025	.025	.025	.025	.025	.025	.025	.025	.025	.025	.025
Sales Revenue						1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250	1,250
Sales Volume						25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000	25,000
Unit Price						.05	.05	.05	.05	.05	.05	.05	.05	.05	.05	.05
Period Cash Flow	-500	-500	-500	-1,000	-625	509	509	509	509	509	509	509	509	509	509	509
PV	-500	-488	-477	-931	-568	451	441	430	420	410	401	391	382	373	364	356
NPV	**$1,455.97**															

Appendix I

Charts and Data for Theoretical Analysis







$Q = 1.5736\ m^3/min = VA$

$A = 0.5\,in\left(\frac{.0254\,m}{in}\right) \times 1\,in\left(\frac{.0254\,m}{in}\right) = .000323\,m^2$

$V_{inlet} = \frac{Q}{A} = \frac{1.5736\ m^3/min}{.000323\,m^2} = 4878\ m/min\ /60 = 81.3\ m/s$

$V_{fan} = \frac{Q}{A} = \frac{1.5736\ m^3/min}{\pi(.1016\,m)^2} = 47.41\ m/min\ /60 = 0.79\ m/s$

$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2$

inlet, fan

$\frac{P_1 - P_2}{\gamma} = \frac{v_2^2 - v_1^2}{2g}$ $\quad P_1 - P_2 = \frac{\gamma(V_2^2 - V_1^2)}{2g} = \frac{11.61\ N/m^3\,(0.79^2 - 81.3^2)}{2\,(9.81\ m/s^2)}$

$P_1 - P_2 = -3910\ N/m^2 = -3910\ Pa\ \frac{1.45 \times 10^{-4}\ psi}{Pa} = -0.567\ psi$

H1(kPa) =	0.9	N2	H2	Q (m^3/s)	H (m)	Airflow (cfm)	Airflow (m^3/s)	Head (in)	Head (m)	Scaled Airflow (m^3/s)	Scaled Head (m)
N1 (rpm) =	3890	0	0	0	76.1986	0	0	1.04	0.026416	0	1374.42448
		100	0.000595	0.001	76.68836	10	0.004719474	1	0.0254	0.002524919	1321.562
(delta)P =	900	200	0.002379	0.002	78.15764	20	0.009438948	0.96	0.024384	0.005049837	1268.69952
ρ =	1.204	300	0.005353	0.003	80.60644	30	0.014158422	0.9	0.02286	0.007574756	1189.4058
g =	9.81	400	0.009516	0.004	84.03476	40	0.018877896	0.86	0.021844	0.010099674	1136.54332
A1 =	0.032429	500	0.014869	0.005	88.4426	50	0.02359737	0.79	0.020066	0.012624593	1044.03398
A2 =	0.000323	600	0.021411	0.006	93.82996	60	0.028316844	0.73	0.018542	0.015149511	964.74026
		700	0.029143	0.007	100.1968	70	0.033036318	0.68	0.017272	0.01767443	898.66216
		800	0.038065	0.008	107.5432	80	0.037755792	0.61	0.015494	0.020199349	806.15282
		900	0.048176	0.009	115.8691	90	0.042475266	0.55	0.01397	0.022724267	726.8591
		1000	0.059476	0.01	125.1746	100	0.04719474	0.5	0.0127	0.025249186	660.781
		1100	0.071966	0.011	135.4595	110	0.051914214	0.47	0.011938	0.027774104	621.13414
		1200	0.085646	0.012	146.724	120	0.056633688	0.44	0.011176	0.030299023	581.48728
		1300	0.100515	0.013	158.968	130	0.061353162	0.43	0.010922	0.032823942	568.27166

		1400	**0.116573**	**0.014**	**172.1915**	**140**	**0.066072636**	**0.4**	**0.01016**	**0.03534886**	**528.6248**
		1500	**0.133821**	**0.015**	**186.3946**	**150**	**0.07079211**	**0.35**	**0.00889**	**0.037873779**	**462.5467**
		1600	**0.152259**	**0.016**	**201.5771**	**160**	**0.075511584**	**0.3**	**0.00762**	**0.040398697**	**396.4686**
		1700	**0.171886**	**0.017**	**217.7392**	**170**	**0.080231058**	**0.25**	**0.00635**	**0.042923616**	**330.3905**
		1800	**0.192703**	**0.018**	**234.8808**	**180**	**0.084950532**	**0.15**	**0.00381**	**0.045448534**	**198.2343**
		1900	**0.214709**	**0.019**	**253.0019**	**190**	**0.089670006**	**0.09**	**0.002286**	**0.047973453**	**118.94058**
		2000	**0.237905**	**0.02**	**272.1025**	**200**	**0.09438948**	**0**	**0**	**0.050498372**	**0**
		2100	**0.26229**	**0.021**	**292.1827**						
		2200	**0.287865**	**0.022**	**313.2424**						
		2300	**0.314629**	**0.023**	**335.2815**						
		2400	**0.342583**	**0.024**	**358.3003**						
		2500	**0.371726**	**0.025**	**382.2985**						
		2600	**0.402059**	**0.026**	**407.2762**						
		2700	**0.433582**	**0.027**	**433.2335**						
		2800	**0.466294**	**0.028**	**460.1703**						
		2900	**0.500195**	**0.029**	**488.0866**						
		3000	**0.535286**	**0.03**	**516.9824**						
		3100	**0.571566**	**0.031**	**546.8578**						
		3200	**0.609036**	**0.032**	**577.7127**						
		3300	**0.647696**	**0.033**	**609.547**						
		3400	**0.687545**	**0.034**	**642.3609**						
		3500	**0.728584**	**0.035**	**676.1544**						
		3600	**0.770812**	**0.036**	**710.9273**						
		3700	**0.814229**	**0.037**	**746.6798**						
		3800	**0.858837**	**0.038**	**783.4118**						

Appendix J

Assembled Vacuum

Body

Filter

Motor Mount

Nozzle Side

Nozzle Inside