Hand-held Vacuum
The K.E.E.N. Team
Team 6

Emily Evanchak
Keith Grauer
Nicholas Rossi
Elaine Sung

Executive Summary

The KEEN Clean handheld vacuum is an effective and efficient new design of a handheld vacuum built from components of a Drill-Master handheld drill. The KEEN team used customer surveys to determine the most important customer needs to be incorporated into the design including, easy to use and handle, durable, safe, and effective. Within the concept selection process, the vacuum design was broken down into five main components: housing, nozzle, fan, filter system, and handle.

Possible design ideas were generated in each category and scored, based on customer need rank weightings. In each category the highest-ranking concepts were chosen to be put into the final design. Now this design is being run through various tests to ensure the best product is put forward including suction-time tests and drop tests. After these tests, modifications are being made in the design to account for the failing in any area. The net present value for this handheld vacuum is approximately $800,000, making this vacuum a good competitor in the hand-held vacuum market.

Table of Contents

1. Introduction

1.1. Problem Statement

The goal is to build a handheld vacuum from parts of an 18V cordless drill. The product will be evaluated by a group of corporate executives, customers, and investors against other the competition's products. The final products will compete in timed competitions to see which vacuum can pick up a plate of rice the fastest. The product must be completed by November 15, 2014. The vacuum must meet the needs of an average customer and be economically viable. Some of the constraints include being cordless and handheld while keeping all vacuumed material inside the body and having an easy to empty collection system. Vacuum must use the battery pack from the drill, as well as the same battery pack connector and DC electric motor, without any changes made to them. The vacuum must incorporate components made using rapid prototyping, CNC, water jet, or casting methods. There can be no use of parts taken from already manufactured handheld vacuums. There must be construction of an alpha and two beta prototypes. The prototypes must be made in a thirty dollar reimbursement limit. This handheld vacuum will be marketed toward consumers in need of an easily maneuverable vacuum that specializes in picking up larger debris.

1.2. Background Information

The final model must use the NiCd battery pack, the DC electric motor, and the battery pack connector/ charger from the Drill-Master drill. The Drill Master is a ⅜" chuck with 0-900 RPM. It has a maximum torque of 7 ft-lbs and a charging time of three to five hours. The recommended air flow through a canister vacuum is 100 ft^3/min and standard vacuum pressure is 20 kPa. The casing of the drill is made from injection molding plastic to create the housing and supports of the drill.

1.3. Project Planning

The full schedule including dates is listed in Appendix A as the Gantt Chart. The design process will begin with an external search. The group will individually search for unique patents, allowing the team to utilize past vacuum designs and implement the best into this design. Then using those patents, will begin a concept generation. Each group member will use sticky notes to roughly sketch possible concepts for the project, where no idea is cast out as far-fetched. After comparing and discussing each concepts, concept groups were made including vacuum housing, handle, nozzle, and fan where each of the concepts were placed into. A list of metrics and needs will be made based on customer needs data. AHP Charts (Ulrich) will be made to determine the ranking of important features in the design, including cost, safety, and effectiveness. Then, the Concept Selection Matrix (Ulrich) will identify the best choice concepts for the final design using the weights identified in the AHP charts. After selecting the concepts of the design, an alpha and two beta prototypes will be built. The second beta prototype will compete against other vacuums.

2. Customer Needs and Specifications

2.1. Identification of Customer Needs

The customer wants a handheld vacuum for quick clean ups, that picks up debris easily and in hard to reach places. Due to time constraints, the team members took on the role of customer to evaluate the customer's needs. The group discussed different vacuuming experiences, and investigated reviews of vacuums on websites like Amazon to see what aspects of the vacuum stood out based on customers good and bad experiences with the vacuum. The most prominent customer needs were safety, durability, ease of use, noise level, ability to suck up debris, lightweight, long battery life, easy to empty, compact, aesthetically pleasing, and high quality.

2.2. Design Specifications

To establish the characteristics to focus on in the design, a list of customer needs and metrics was made, where each customer need is made into a metric of how each can be put into the design. This way no customer need is left out of the final product. The list of metrics incorporated into the design is, conduction of housing, strength of housing, drop test performance, total weight, max nozzle size, containment volume, max decibels, volumetric flow rate, power consumption, motor speed, time to empty, and size of housing. This chart of metrics vs customer needs is seen as the QFD Chart in Appendix B. The characteristics deemed most important were conduction of housing, strength of housing, drop test performance, total weight, max nozzle, containment volume, max decibels, volumetric flow rate, power consumption, motor speed, time to empty, and size of housing. In the dust cup category, effectiveness was weighted with the most importance. In the nozzles, durability was the most significant feature. Durability and ease of use were the most crucial characteristics in the selection of the handle style. In the fan concepts, durability and effectiveness were the highest ranked. To identify what features were most important to the consumer, various features of a vacuum were weighted against each other in AHP Charts. In an AHP Chart, metrics specific to each concept category were ranked against each other in terms of 1,2,3,4, and 5. In the box mirroring the 1-5 value, the inverse of that value is entered. Then the total is calculated and then each value is divided by the whole to find the percent of importance. An example of an AHP chart is shown in Figure 2.1, the rest of the AHP charts are shown in Appendix A.

3. Concept Development

3.1. External Search

Before brainstorming ideas, the TRIZ method of problem-solving was applied by conducting an external search individually; the main focus of the research was on patents providing information on current vacuum technology. The patents generated insights and benchmarking on the different housing shapes, nozzle ideas, and filter technology that was possible. Designs from companies known for their vacuum products such as Shark© and Dyson© were also consulted. Several patents were selected based on competency and uniqueness and were presented to the team for discussion. See Chapter 6--References for a list of patents consulted for this project.

3.2. Problem Decomposition

To understand each process that needed to undergo design and materials consideration, a black-box diagram (Diagram 1) of the vacuum was created

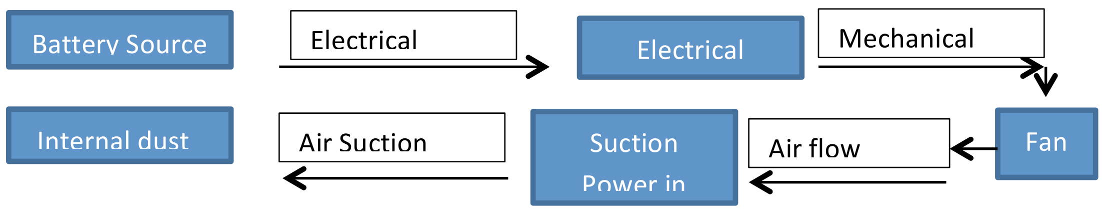


Diagram 1: Black-box diagram outlining each physical and engineering process the vacuum undergoes once

3.3. Concept Generation

The next step in the concept generation was to brainstorm random ideas on post-it notes individually before combining all the ideas together for team consideration. The patents and current vacuum technology influenced many ideas. Once the brainstorming session was completed, the ideas were broken into sections by vacuum part: the body/housing, the nozzle, the handle, the bag/filter, and the fan. Concepts that were selected for concept selection were judged by stability, maneuverability, and creativity.

3.3.1 Handle Selection

The concepts for the handle of the vacuum chosen to move on to concept selection were the "throttle/gun" style and the "basket" design. The "throttle/gun" style (Figure 1) is a sturdy design because it is stubby and close to the body of the vacuum, therefore providing easy maneuverability for the user. In this case, the handle is placed on the top of the vacuum. For the "basket" design, the handle is rounded and also placed on top of the vacuum. The benefits of this design are that it is easy to grasp and hold.

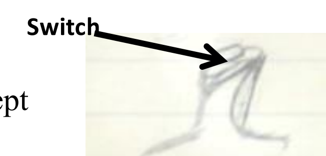


Figure 1 —Concept of "throttle/gun" handle

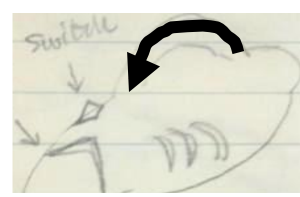


Figure 2—Concept of "basket" handle

3.3.2 Container Selection

The concepts of the waste container of the vacuum that moved on to concept selection are a plastic bag, an external clip-on plastic container, and an internal dust cup. Though not pictured, each concept has two choices; the first is the design with a screen filter and the second is the design with a cyclone for filtering. During the concept generation, it was decided by the team to have one or the other types of filtering but not both; although the filtering concept alternated, the designs stayed constant between the two choices.

The idea behind the plastic bag concept (Figure 3) was to place a generic plastic bag at the end of the vacuum where debris can easily

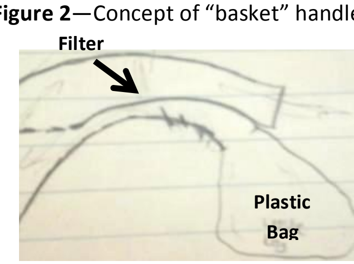


Figure 3—Plastic bag with filter for

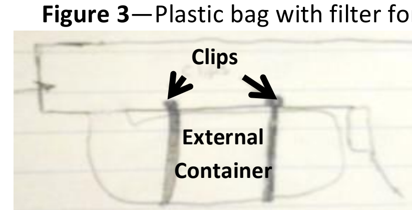


Figure 4—External clip-on

fall into and be stored. The benefits to this concept were the possible low price of materials and the physical flexibility of storage. The external clip-on container (Figure 4) is very similar to the plastic bag concept except for the materials. Additionally, the container was visualized to be placed near the middle of the vacuum so debris would fall directly into the container without much direction. The benefit to this design would be the volume of the container and the ease of cleaning and emptying. Finally, the internal dust cup is located near the nozzle of the vacuum inside the body. Pictured in Figure 5 is the idea of the cyclone filtering with the dust cup surrounding the cyclone. This would be similarly designed for the screen filter as well. The benefit of this concept is the ease of flow of the debris to the container.

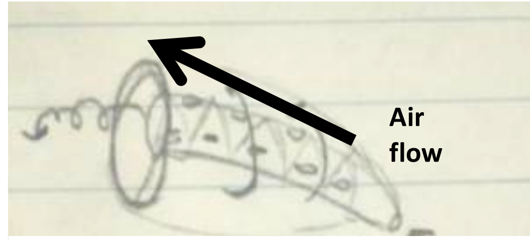


Figure 5—internal dust cup for containment

3.3.3 Nozzle Selection

Out of all the vacuum parts, the nozzle had the most ideas generated from brainstorming. The ideas chosen for concept selection were an extendible flexible nozzle, an extendible stiff style, an agitator lever concept, an agitator brush, a snub nose, or a standard wide mouth. The

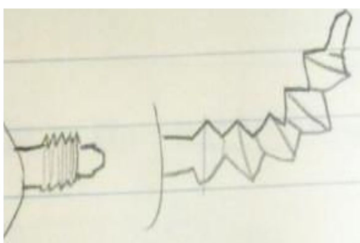


Figure 6—Extendible flexible nozzle

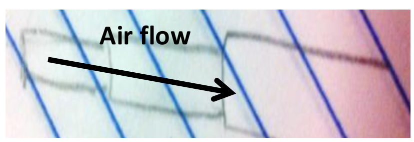


Figure 7—Extendible stiff nozzle

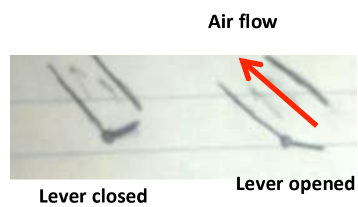


Figure 8—Agitator-lever concept

concept of extendible signifies the ability of the nozzle to elongate or shrink by changing shape. For example, in the extendible flexible nozzle (Figure 6), the nozzle acts like a bendable straw in that it can both extend out and retract with an accordion-like form. For the extendible stiff nozzle (Figure 7), the nozzle has the form of a telescope in that it has a large base with compartments of the nozzle gradually decreasing up to the end. Both were designed with the idea of convenience and adaptability in mind.

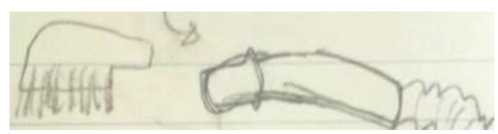


Figure 9—Agitator-brush attachment to nozzle

For the agitators (Figure 8), the main concept was a design that could somehow facilitate collecting debris by “kicking up” the wanted objects with an active part of the nozzle. The agitator-lever concept was designed to have a tube-like nozzle with a movable platform at the bottom of the nozzle that could be flipped up and down to kick the debris into the way of the suction. For the agitator-brush concept (Figure 9), the nozzle was designed similarly to a

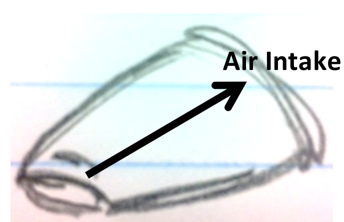


Figure 10—Snub-nose nozzle

hairbrush in that it could scrape the debris from the floor easily and thus push it more towards the suction; in the agitator-brush is drawn as an attachment to a hose leading to the body of the vacuum.

The design that was a reference for the other concepts during concept selection was the snub-nose nozzle (Figure 10). This idea of a stubby shape for the nozzle was inspired by the Shark® handheld vacuum. Unlike the extendible or the agitator nozzles, the snub-nose is short and very close to the body of the vacuum. Also, the hole for suction is located beneath the nozzle.

Finally, the last nozzle design considered was the standard wide mouth nozzle (Figure 11). This idea was from standard house vacuums; the nozzle is designed to look and function similarly to the square-based nozzles of full size vacuums. In the case of the handheld vacuum, the square-shaped nozzle would be similarly attached to the body of the vacuum like the snub-nose design.

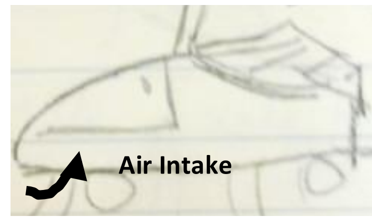


Figure 11—Standard wide

3.3.4 Fan Selection

Designs for a fan that would create sufficient suction for the project were decided on next. There were a total of four fan concepts: a paddle fan (Figure 12), a screw fan (Figure 13), a pump fan (Figure 14), and a centrifugal fan (Figure 15). The design of the screw fan has blades in a spiral formation on an axle that is capable of spinning at high speeds to create suction power. The pump fan consists of a pump that could rapidly propel air through the

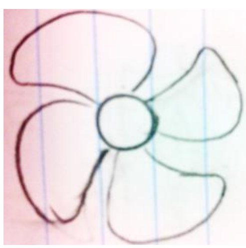


Figure 12—Paddle

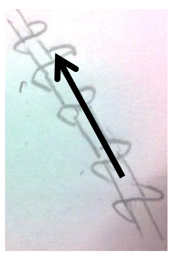


Figure 13—Screw Fan

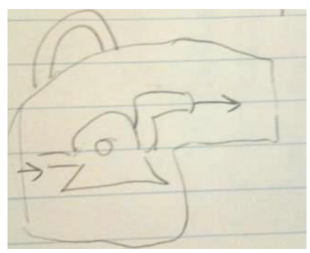


Figure 14—Pump Fan

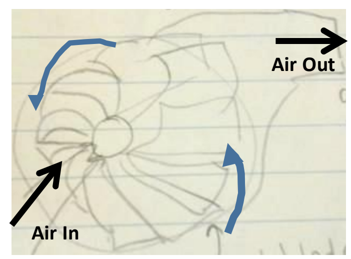


Figure 15—Centrifugal Fan

vacuum system for suction power. The simplest fan in consideration was the paddle which was the basic fan design of blades attached to an axle. Finally, we considered the centrifugal fan, which is used in several current vacuum designs and was our standard to compare the others to.

3.3.5 Housing Selection

After all the internal components had been narrowed down for concept selection, the final component of the vacuum to be decided on was the housing. There were two housing designs that moved on to concept selection: the gun body design and the oblong-shaped design. The oblong-shaped concept (Fig. 16) was based off the Shark ® hand-held vacuum. The gun design concept (Fig. 17) was created with the idea of maintaining the original drill body.

Figure 16—Oblong Concept

Figure 17—Gun Concept

3.4. Concept Selection

After the concepts had been grouped into appropriate categories, each specification was assessed for valuable qualities. The first step in this process included an evaluation of handheld vacuums and evaluating each important quality based on the customer needs discussed earlier. An example of this is *Concept Selection Table 4: AHP Fan Weightings*. This table shows the relative importance of each quality associated with the fan. In this case, durability and effectiveness tied for the most important quality, while cost and power usage fell below these in importance. Now that the qualities of each specification had been weighted, the individual concepts could be analyzed on a legitimate scoring basis. The centrifugal fan was ranked with the highest score of 4.22. *Concept Selection Table 1: Housing Concept Selection* and *Concept Selection Table 2: Nozzle Concept Selection* show scorings for the housing and nozzle selections. In housing, the Oblong shape won with a rank of 3.32, compared to the gun-shaped score of 3. In the nozzle category, the Snub-Nose was selected with the high score of 4.11. This process was repeated for each specification, including the housing, nozzle, fan, container, and handle. Referring to *Concept Selection Table 3: Nozzle Concept Selection*, the weightings shown in the left column directly illustrate the importance of each quality a nozzle holds. In this case, the most important qualities of a nozzle are the durability and the effectiveness. Adaptability, Cost, and Aesthetics would be completely trivial without the proper durability and effectiveness. With each specification ranked numerically, the complete assembly became apparent. Now, the concepts had to be meshed into one compact design that maintains its mechanical integrity.

4. System Level Design

4.1 Overall Description

The design assembly is shown in Figure 18, labeling each part. With the major components selected, the major concern design concern was designing a product allowing them all to work together in a compact and ergonomic whole.

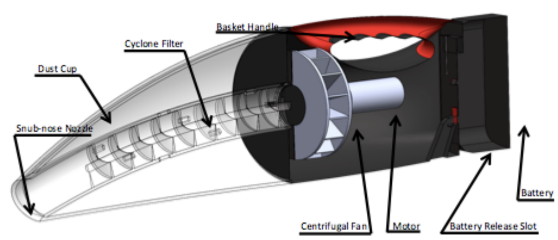


Figure 18-- Vacuum Component Layout

The overall shape was strongly influenced by existing cordless vacuums, as the structure has several key advantages. First, the airflow path and drive system are linearized, simplifying the fabrication process, and potentially reducing energy loss to the airflow. Secondly, the elongated profile maximizes the device's ability to reach out-of-the-way locations. Third, as the battery pack is the heaviest component, its position behind the handle will act to balance the vacuum in the user's hand. Finally, the translucent dust cup is front mounted to help identify when it must be emptied, and simplify the removal process to do so. The vacuum consists of three major components; the dust cup, the main housing, and the driving assembly.

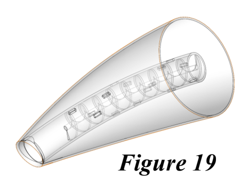


Figure 19

The dust cup (**Figure 19**) includes the snub-nose nozzle, the internal cyclone, and sets the style for the oblong body. The cross-section is elliptical to easily indicate its orientation relative to the rest of the body, and to allow the nozzle to be cleanly integrated with the cup's profile. The main focus of the dust cup is the internal cyclone, which replaces the filter in traditional vacuums. The design was created for larger systems, and needed to be adapted to fit in the smaller space. As such, the cyclone is a single path, spiraling through the center of the cup, towards the fan. The small radius of the spiral forces particulate to exit the air stream through vents on the outside edges, where it is contained in the dust cup. The clean air continues through the cyclone until it reaches the main body, and the fan contained within.

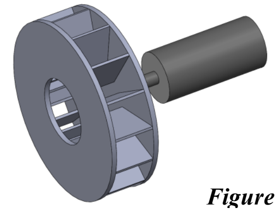


Figure 20

Figure 21

The driving assembly (**Figure 20**) converts electrical power from the battery pack, into air flow. The drill motor receives electrical power, and changes it into rotational motion, which is transferred to the centrifugal fan to drive air flow.

The main housing (**Figure 21**) acts to connect the individual pieces while holding them in the correct positions. Two sets of vents on either side of the housing release the fan exhaust, and provide ventilation to cool the motor. To improve the aesthetics of the product, the connection for the battery pack extends over the release button to make the profiles are flush. An internal lever exiting the bottom of the housing allows the battery pack to be removed from this design.

4.2 Preliminary Theoretical Analysis

There are two focuses of concern in this design; the energy consumption in the drive system, and the effectiveness of the cyclone filter. To consider the energy use, typical vacuum cleaner properties are necessary. The air flow rate is around 100 cubic feet per minute, and vacuum pressure is 20 kilo-Pascals. Using the values, there will be a 675 Watt draw on the batter, which will consume the listed 1300 mili-amp-hours in 2 minutes (Calculation 1). This is clearly not ideal usage conditions, so performing the calculations in reverse, starting with a running time of 15 minutes, while holding the air flow rate constant, results in a vacuum pressure of 1.4 kilo-Pascals (Calculation 2). While a much lower pressure, this is not unreasonable, and the increase to 15 minutes of run time will allow the system to actually function.

To consider the effectiveness of the cyclone filter, the Solidworks fluid flow simulation was employed. The results can be seen in *Figure 22*. The line color changes to repressent the velocity of the flow, with warmer colors indicating higher flow velocities. From the analysis, it can be seen that the flow is primarily contained within the cyclone body, however, there are two noticable failings.

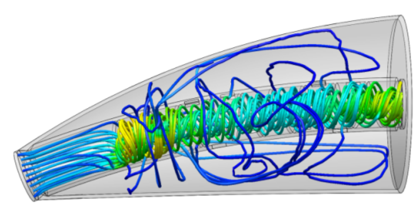


Figure 22

The first is that the flow velocity decreases in the center of the cyclone, which will lower the filtering capabilities along the effected length. And second, a small volume of air re-enters the cyclone at the very end, which creates the possibility of dirty air being pulled into the fan. These results indicate that the cyclone design is a feasable alternative to a filter, but the current design will require modifiction before it can be effectivley implemented.

5. Detailed Design

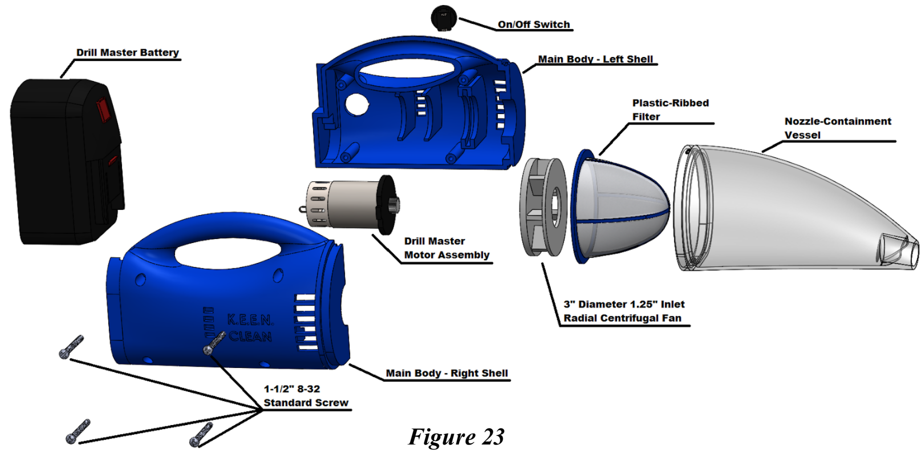


Figure 23

As can be seen in Figure 5.1, the product is primarily an axially-aligned clam shell design. The battery, motor, fan, filter, and nozzle form a direct line through the center of the device, while the two halves of the body screw together around them to direct airflow, and hold each part in the correct location. The main body houses the motor assembly, along with the fan, and the electrical systems. It is secured with four off the shelf 8-32 screws, and forms the platform upon which all the other components rest. The battery, filter, and nozzle are held onto the main body with rail and clip systems, to expedite assembly time for charging and emptying.

5.1 Modifications to Proposal Sections

Since the time of the proposal submission, the design has gone through strategic changes. First, the cyclonic filter system was removed from the design and replaced with the next highest ranked container for vacuum, the internal dust cup with a filter. Because of the difficulty of assembling the cyclone, this design component was determined by the team to not be the most efficient use of the team's time or resources, when the next highest scoring option would be just as effective with fewer complications. The schedule to date is displayed in Appendix B in the expanded and updated Gantt Chart. This update includes the completion of the beta prototype and includes testing dates and the final design.

5.2 Final Theoretical Analysis

The main focus of a vacuum is its suction ability, which in industry is evaluated with suction head, and air flow rate. When designing a cordless vacuum, the issue of battery life must also be considered. An ideal usage duration was chosen to be fifteen minutes. Using the Ni-Cd batteries listed as 18V and 1300mAhr, with a discharge duration of 15 minutes (Appendix C-1) yields an energy of 84,240J. This energy is transmitted from the battery to the fan by means of the motor. At the fan, the energy is used to move air through the system. The fan in the system is a radial centrifugal design, which operates with an average efficiency of 70%. This reduced energy will drive a flow through the vacuum nozzle, at a rate which can be calculated using a simplified version of the first law of thermodynamics (Appendix C-2). This shows that at the estimated efficiency, the system will be drawing approximately 150 cubic feet per minute of air through the filter. This is within the bounds of standard vacuum recommendations, and shows that the system is viable.

5.3 Component and Material Selection

With the functional beta prototype complete, the team could note the specifics of the system in terms of pros and cons. This assessment generated a copious amount of informal data that could be directly related to some of the tables found earlier in this report that detail several customer requirements, specifically durability and ease of use. These correlations led to several material considerations for the mass production unit with a focus on materials that can withstand the loads of a hand-held vacuum, are lightweight enough to be easily held and manipulated, are cost effective, and are environmentally sound. With these factors in mind, the team also considered the manufacturing processes associated with each material option in terms of mass production. The majority of the materials chosen in the mass production unit should provide options to very efficient processes to increase the net product value. Thus, ABS (Acrylonitrile Butadiene Styrene) thermoplastic was chose for exactly this. ABS plastic provides durability levels that far surpass the loads this hand-held vacuum will be experiencing. The chemical structure provides stable mechanical properties within a large range of temperatures that includes extremities not found commonly found in the environment. This flame-retardant material (at normal temperatures) is also extremely lightweight, especially when compared to other materials used for similar applications. Coincidentally, ABS is a very affordable and recyclable thermoplastic due to its reconstructive abilities. Therefore, the environmental impact on the use of this material will be close to none. With the primary material chosen, specific component materials were then decided. The housing, nozzle, centrifugal fan, and filter structure will be mass-produced with the ABS thermoplastic. The on-off switch will be an off-the-shelf component, specifically the DigiKey EG4763-ND Switch. The filter screen to fit over the filter structure will also be off-the-shelf, as it is just a simple screen with very small holes to allow airflow. Other materials and components include four assembly screws, the drill master motor assembly, and the drill master battery.

5.4 Fabrication Process for the Mass Production Unit

The fabrication process needs to not only be efficient in terms of time, but it also needs to be efficient in terms of cost. Injection molding of the ABS thermoplastic components meets these requirements perfectly. Thus, an aluminum mold will be produced for the nozzle, the centrifugal fan, the filter structure, and the housing. The housing will have to be split vertically down the axis of the vacuum to allow for the actual assembly of the components, and thus a mold will need to be produced for each side. Some post-processing may be necessary on each of these components to provide a smooth and clean finish. The two sides of the housing will be conjoined using four 1-1/2” 8-32 standard screws, holding the inner components in place. This fabrication process consists of just a few molds, some over-the-shelf components, and a four-screw assembly, which proves to be both efficient and cost effective.

5.5 Industrial Design

The product provides a smooth, symmetric clamshell design. The housing includes a handle that conforms perfectly to the user's hand with a slight angle to tilt the vacuum forward. This handle is positioned at the center of mass of the entire product to provide a natural balance. As mentioned in a previous section, the battery, filter, and nozzle are held onto the main body with rail and clip systems to expedite assembly time for charging and emptying. To add to this, the diameter of the nozzle near its connection to the main body naturally fits inside the average hand to provide an effective grip. The overall body has a flat bottom so that the product can be safely and easily placed down. The switch is located on the upper left side of the housing for easy access and use. The left side was chosen because, according to Scientific American, 70-95% of people are right handed, which means the product will be held with the right hand and the switch will be operated with the left [11]. The air vents are positioned on the sides of the housing so that the outlet flow does not interact with the user. Finally, the team's logo "K.E.E.N. CLEAN" is positioned on the housing for aesthetic pleasure.

5.6 Detailed Drawings

When designing a consumer product, a large focus is always placed on making it simple to use, and easy to understand. The KEEN Clean Vacuum is no exception to this idea. The product consists of only nine different components, and four of those are off-the-shelf items. These off-the-shelf items are the battery, motor assembly, on/off switch, and 8-32 screws. The purpose and location of each of the previous parts will be identified during the following examination of the remaining five custom built components.

The first custom component is the fan (Appendix D: Detailed Drawings 1), which is arguably the most important component of any vacuum. The fan is of the radial centrifugal design most common in canister vacuums. It is slightly smaller than average with an outer diameter of only 3" due to power consumption constraints imposed by the battery, but the suction it provides is only slightly reduced when used in such a compact device. The fan mounts directly onto the motor shaft as both a power source, and an alignment system. In order to protect the fan from damage a filter (Appendix D: Detailed Drawing 2) is included further up the flow path. The design consists of a synthetic filter held between two plastic ribs, which are in turn mounted to a plastic disk. The bowed design increases the surface are of the filter, and decreases the possibility of it becoming fully blocked with debris. The plastic base fits into a depression on the inside of the containment vessel to be held in place against the main body when in use. The ring is also semi-symmetric to allow easy alignment when cleaning out the containment vessel. The previously mentioned containment vessel (Appendix D: Detailed Drawing 3) also acts as the vacuums nozzle. The front of the vessel is an oblong hole where air and debris enter the system and pass a small rubber flap, which closes to keep the debris contained when the vacuum is not in use. The center portion of the vessel is simply a large empty volume to contain the debris. On the far side of the vessel, the component is the connection point, where the vessel mates with the main body of the vacuum. The edges are matched to the inset of the body, and two offsets match with groves on the body's edge to hold the assembly together. The final two components (Appendix D: Detailed Drawing 4) are nearly mirror images of each other, as they form the main body of the vacuum. Each piece has three sets of standoffs which hold the motor in place, and ensure proper alignment of the fan mounted to it. At one end, a set of grooves allow the containment vessel to hold onto the body, and secure the filter between the components. On the opposite end, the pieces match to form a connection point for the battery, with a shape mimicking that found on the connection point of the Drill Master drill. The only differences between the mirrored parts are the inclusion of cutout on the left side for the on/off switch, and the mounting points for the screws. On the left side, the mounting areas are threaded to maximum depth for 8-32 threads, while on the right side, the mounts are accessible from the outside of the assembly, and are free floating with the screws, so that the two parts can be tightened after being assembled.

5.7 Economic Analysis

5.7.1 Unit Production Cost

Listed in *Table 1: Bill of Materials including costs of parts, materials, labor and overhead charges* are the estimated costs generated in the mass production of each unit of the vacuum, assuming annual production volume is 100, 000 units. The main costs are the variable costs, labor costs, and fixed costs. Overhead costs such as taxes, marketing, insurance, and maintenance were also considered. Once all the costs were accounted for, the total cost of a unit including overhead costs $9.89.

5.7.2 Business Case Justification

Overall, this enterprise is a good investment for several reasons. For pricing, since the unit production cost is a little under $10 and if the distributor is charged 1.5 times that amount, the retail price should be at least double the distributor price. Therefore, the price is decided to be set at $29.99; this is also another reason to why this enterprise is a good investment because the overall price is relatively affordable for most Americans. Furthermore, according to the NPV calculated over 4 years at 100,000 units per year (*Table 2: Financial Model of Project NPV at 10% discount rate*), the NPV value is a positive $4,997, 000, meaning that the enterprise will result in a profit.

5.8 Safety

All wires and electric devices such as the motor are placed inside casings that are screwed together; additionally, there is no risk of electrocution through the outlet as this is a cordless vacuum. There are no exterior objects that would cause direct harm to the user such as sharp objects. The safety standards that the product complies to are UL1017 regarding vacuum cleaners, blower cleaners, and household floor finishing machines, UL60745 regarding the safety of hand-held motor-operated or magnetically driven electric tools, and IEC60312 regarding vacuum cleaners for household use.

6. Testing

The prototype will be tested for durability, capability, and overall functionality. Parts and components that will be specifically observed are the centrifugal fan, the cyclone technology, and the strength of the housing. To test the cyclone technology and the centrifugal fan for performance and durability, a suction test will be performed. For this procedure, the vacuum will need to be fully assembled and clean. There will also need to be a variety of forms of debris for vacuuming such as a mixture of leaves, small rocks, rice, and dust. To begin, the debris will be spread out in a line in front of the vacuum on a carpeted surface. Once the vacuum is running, the user will slowly run the nozzle over the debris, making sure most of the debris is sucked up. At the end of the line of debris, the vacuum will be turned off and the nozzle removed to be able to observe the cyclone. If less than 5% of the debris remains in the cyclone and if the cyclone remains fully intact, the cyclone technology will have passed the performance test. Likewise, if the centrifugal fan is also intact, it will have passed the test as well. To test the housing durability, a drop test will be performed. For this test, no outside equipment is needed besides the vacuum. In the drop test, the user will stand on flat ground and hold the vacuum above the head. The user will then release the vacuum onto a hard surface normally found in the flooring of houses such as a concrete or wood floor. The vacuum housing will then be observed for any cracks or fractures. If no damage occurs, the vacuum body will have passed the drop test.

7. Conclusion

The design is currently in the midst of the design process. The vacuum began with an external search into vacuum concepts leading to a customer survey to find a focus for the characteristics of the vacuum. After generating concepts for different components of the drill, different characteristics of the design were rated against each other and the key features were selected. Using these rankings, each of the final concepts was selected. The second draft of the model is displayed on the cover page. This project should be allowed to proceed because based on the research done by the team members and the tests done so far, the design will meet all of the constraints of the proposed design and also meet the customer needs making a good match against its competitors. One special feature of the vacuum that puts this product ahead of the competition is the nozzle design. The nozzle is slightly slanted and has a structured and somewhat pointed opening to facilitate use and allow the user to maneuver small places and corners. In addition to being compact and easy to handle, the vacuum has the reliable feature of an internal filter screen system. Customers would desire to purchase this because the filter technology promotes an efficient and a reliable method of cleaning by using a method that consumers already know and trust. Currently, the market for handheld vacuums is promising for several reasons. One reason is that it is a commodity; most house owners routinely clean their living quarters, and oftentimes the consumer requires a device to clean small areas or prefers a lighter and easier method of vacuuming over the traditional full-sized vacuum. Another reason the hand-held vacuum can thrive in the market is that the majority of U.S. citizens are middle class, meaning that most consumers will have a house and have the income to purchase cleaning technology such as the vacuum. In conclusion, after patent research and concept generation and selection, and the building and testing of the alpha and beta prototypes, the hand-held vacuum's design is mostly completed and will be carried through to building the final hand held vacuum design.

8. References

[1] Conrad, Wayne E., Helmut G. Conrad, and Ted Szylowiec. Air Flow Passage for a Vacuum Cleaner. GBD Corporation, assignee. Patent US 8015659 B2. 13 Sept. 2011. Print.

[2] Eriknsson, Henrik. Agitator with Cleaning Features. Electrolux Home Care Products, Inc., assignee. Patent US 8601643 B2. 10 Dec. 2013. Print.

[3] Squires, John. Dirt and Air Separation. Squires John, assignee. Patent US 1664092 A. 1 Nov. 1924. Print.

[4] Product Design and Development, 5th Edition, K. Ulrich and S. Eppinger, Irwin McGraw, 2010

[5] Proett, Mark Anton. 1977. Cordless vacuum cleaner. U.S. Patent 4, 011, 624A filed August 25, 1975,

and issued March 15, 1977.

[6] Groff, Timothy. 2011. Handheld vacuum cleaner. U.S. Patent 8 069529 B2 filed October 21, 2009 and issued December 6, 2011.

[7]Milligan, Michael A. 2013. Handheld cordless vacuum cleaner. U.S. Patent 8549704 B2 filed October 19, 2010 and issued October 8, 2013.

[8]Hult, David. R. 1991. Portable Handheld vacuum cleaner. U.S. Patent 5025529 A filed September 17, 1990 and issued June 25, 1991.

[9]Frantzen, Thommy. 2007. Handheld vacuum cleaner. U.S. Patent 7958597 B2 filed March 15, 2007 and issued June 14, 2011.

[10]Schuler, Gustav. 1977. Air intake filter with separator state. U.S. Patent 4162905 A filed December 7, 1977 and issued July 31, 1979.

[11]"Why Are More People Right-handed?" *Scientific American Global RSS*. Scientific American, 1 Nov. 2001. Web. 17 Nov. 2014.

9. Appendices
Appendix A – Project Management

Team Roles & Qualifications:

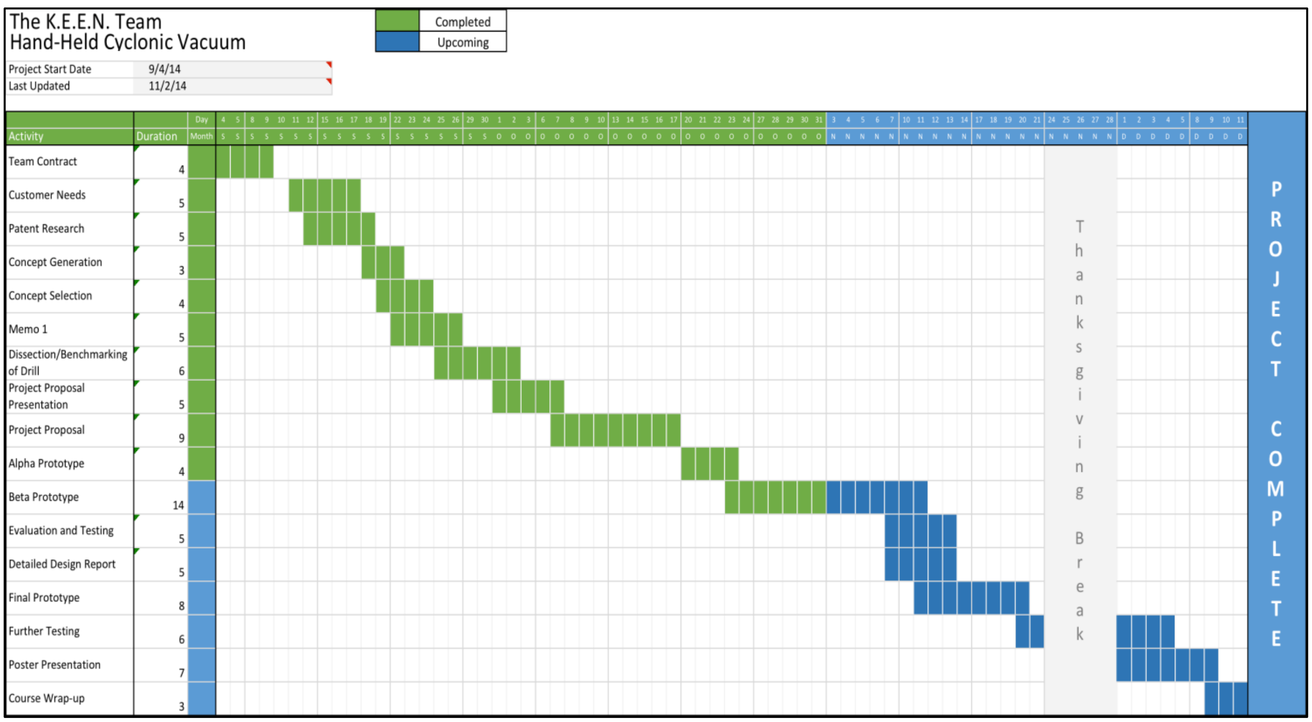
Keith
Strengths: Adaptable, Confident
Weakness: Passive

Nick
Strengths: Focused, Organized
Weakness: Impatient

Elaine
Strengths: Hard Worker, Realistic
Weakness: Over-Estimates Capabilities

Emily
Strengths: Cooperative, Detail-Oriented
Weakness: Indecisive

Gantt Chart



Appendix B – Tables and Charts

QFD Chart

	Conducting of housing	Strength of housing	Drop test performance	Total weight	Max nozzle size	Containment volume	Max Decibels
Safe to Use	X	X	X	X			X
Durable		X	X				
Easy to Use			X	X	X	X	
Not too loud							X
Sucks up rice					X	X	
Easy to hold				X			

AHP Table 1

Bag/Filter AHP Chart								
	Capacity	Easy to use	Containment ability	durability	effectiveness	cost	Total	Weight
Capacity		0.33	0.50	0.50	0.33	0.50	2.17	0.08
Easy to use	3.00		1.00	0.50	0.33	3.00	4.83	0.18
Containment Ability	2.00	1.00		1.00	0.50	0.50	3.00	0.11
Durability	2.00	2.00	1.00		1.00	2.00	6.00	0.22
Effectiveness	3.00	3.00	2.00	1.00		2.00	8.00	0.29
Cost	2.00	0.33	2.00	0.50	0.50		3.33	0.12
							27.33	

Nozzle AHP Chart							
	Durability	Adaptability	Cost	Aesthetics	Effectiveness	Totals	Weights
Durability		2.00	3.00	3.00	2.00	10.00	0.34
Adaptability	0.50		0.50	2.00	0.33	3.33	0.11
Cost	0.33	2.00		2.00	0.33	4.67	0.16
Aesthetics	0.33	0.50	0.50		0.33	1.67	0.06
Effectiveness	0.50	3.00	3.00	3.00		9.50	0.33
						29.17	

AHP Table 2

AHP Table 3

Body/Housing and Handle AHP Charts							
	Safety	Durability	Cost	Aesthetics	Easy to handle	Totals	Weights
Safety		1.00	2.00	3.00	2.00	8.00	0.30
Durability	1.00		2.00	3.00	1.00	7.00	0.26
Cost	0.50	0.50		2.00	0.50	3.50	0.13
Aesthetics	0.33	0.33	0.50		0.33	1.50	0.06
Easy to handle	0.50	1.00	2.00	3.00		6.50	0.25
						26.50	

AHP Table 4

Fan Selection AHP Charts						
	Cost	Durability	Effectiveness	Power Use	Totals	Weights
Cost		0.50	0.50	1.00	2.00	0.14
Durability	2.00		1.00	2.00	5.00	0.36
Effectiveness	2.00	1.00		2.00	5.00	0.36
Power Use	1.00	0.50	0.50		2.00	0.14
					14.00	

Concept Selection Tables:

Table 1

Concept Selection for Housing of Vacuum					
		Oblong		Gun-Shaped	
	Weight	**Rating**	**Weighted Score**	Rating	Weighted Score
Safety	0.3	**3**	**0.9**	3	0.9
Durability	0.26	**4**	**1.04**	3	0.78
Cost	0.13	**3**	**0.39**	3	0.39
Aesthetics	0.06	**4**	**0.24**	3	0.18
Easy to handle	0.25	**3**	**0.75**	3	0.75
Total Score Rank Continue?			**3.32** **1** **Yes**		3 2 No

Table 2

Concept Selection for Nozzle of Vacuum											
		Extendible Flexible		Stiff Long-nose		Agitator Lever		**Snub Nose**		Standard Wide Mouth	
	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	**Rating**	**Weighted Score**	Rating	Weighted Score
Durability	0.34	2	0.68	1	0.34	2	0.68	**4**	**1.36**	3	1.02
Addaptability	0.11	5	0.55	4	0.44	2	0.22	**3**	**0.33**	2	0.22
Cost	0.16	3	0.48	3	0.48	2	0.32	**5**	**0.8**	4	0.64
Aesthetics	0.06	3	0.18	1	0.06	2	0.12	**5**	**0.3**	4	0.24
Effectiveness	0.33	4	1.32	2	0.66	1	0.33	**4**	**1.32**	3	0.99
Total Score Rank Continue?			3.21 2 No		1.98 4 No		1.67 5 No		**4.11** **1** **Yes**		3.11 3 No

Table 3

Concept Selection for Handle of Vacuum					
		Joystick		**Basket**	
	Weight	Rating	Weighted Score	**Rating**	**Weighted Score**
Safety	0.3	2	0.6	**3**	**0.9**
Durability	0.26	3	0.78	**4**	**1.04**
Cost	0.13	3	0.39	**3**	**0.39**
Aesthetics	0.06	2	0.12	**3**	**0.18**
Easy to handle	0.25	3	0.75	**3**	**0.75**
Total Score Rank Continue?			2.64 2 No		**3.26** **1** **Yes**

Table 4

Concept Selection for Fan of Vacuum									
		Centrifugal		Paddle		Pump		Screw	
	Weight	**Rating**	**Weighted Score**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	0.14	**3**	**0.42**	3	0.42	2	0.28	3	0.42
Durability	0.36	**4**	**1.44**	2	0.72	2	0.72	3	1.08
Effectiveness	0.36	**5**	**1.8**	3	1.08	1	0.36	2	0.72
Power Use	0.14	**4**	**0.56**	3	0.42	1	0.14	2	0.28
Total Score Rank Continue?			**4.22** **1** **Yes**		2.64 2 No		1.5 4 No		2.5 3 No

Table 5

Concept Selection for Container of Vacuum											
		Internal dust cup w/ filter		**Internal dust cup w/ cyclone**		Plastic Bag w/ filter		Clip-on external w/ filter		Clip-on external w/ cyclone	
	Weight	Rating	Weighted Score	**Rating**	**Weighted Score**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Capacity	0.08	3	0.24	**2**	**0.16**	5	0.4	4	0.32	4	0.32
Easy to use	0.18	3	0.54	**4**	**0.72**	2	0.36	4	0.72	4	0.72
Containment ability	0.11	5	0.55	**5**	**0.55**	1	0.11	3	0.33	3	0.33
Durability	0.22	4	0.88	**4**	**0.88**	1	0.22	3	0.66	3	0.66
Effectiveness	0.29	3	0.87	**4**	**1.16**	1	0.29	2	0.58	3	0.87
Cost	0.12	3	0.36	**3**	**0.36**	4	0.48	3	0.36	3	0.36
Total Score Rank Continue?			3.44 2 No		**3.83 1 Yes**		1.86 5 No		2.97 4 No		3.26 3 No

Component	Quantity	Total Unit Variable Costs ($)	Labor Costs ($)	Total Unit Fixed Cost ($)	Total Cost ($)
Housing/ Machined Casting	2	0.50 ea	0.05 ea	150 K	2.60
Tube of cyclone	1	0.40	0.10		0.50
One-inch 8-32 Screws	4	0.03 ea	0.05 ea		0.32
DigiKey EG4763-ND Switch	1	0.25	0.10		0.35
Centrifugal Fan	1	2.00	0.10		2.10
Drillmaster Electric Motor and Battery	1	2.00	0.15		2.15
Packaging		0.50	0.10		0.60
				Unit Production Cost	8.62
Overhead Charges (15% of Unit production cost)					1.29
Assumed Annual Production Volume N = 100 K units				**Total Cost**	9.89

Table 1: Bill of Materials including costs of parts, materials, labor and overhead charges.

	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	-1000	-1000	-1000	-1000												
Ramp-up Cost			-1000	-1000												
Marketing & support cost				-129	-129	-129	-129	-129	-129	-129	-129	-129	-129	-129	-129	-129
Production cost					-989	-989	-989	-989	-989	-989	-989	-989	-989	-989	-989	-989
Production volume					100	100	100	100	100	100	100	100	100	100	100	100
Unit production cost					-.009	-.009	-.009	-.009	-.009	-.009	-.009	-.009	-.009	-.009	-.009	-.009
Sales revenue					3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000	3000
Sales volume					100	100	100	100	100	100	100	100	100	100	100	100
Unit price					0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Period Cash Flow	-1000	-1000	-2000	-2129	2082	2082	2082	2082	2082	2082	2082	2082	2082	2082	2082	2082
Present value, r = 10%	-909	-826.	-1503	-1454.	1293	1175	1068	971	8832	803	730	663	603	548	498	453
Project NPV	**4997**															

Table 2: Financial Model of Project NPV at 10% discount rate

Appendix C – Theoretical Analysis

Calculation 1

$$P = V * \frac{C}{t}$$

$$P = 18V * \frac{1300mAhr}{0.25hr} = 93.6\,W$$

$$E = P * t = 93.6W * 900sec = 84240J$$

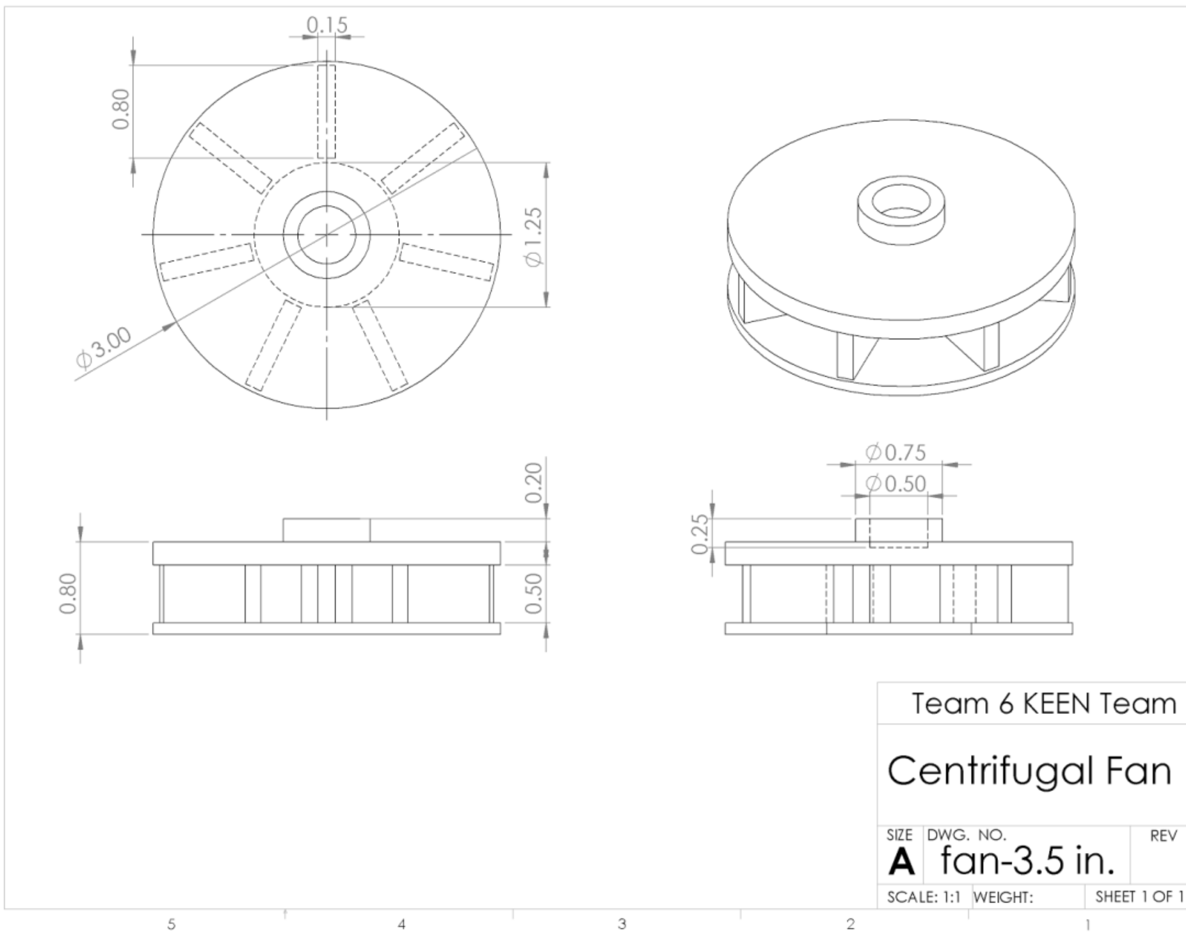
Calculation 2

$$Flow\ velocity = \sqrt[3]{\frac{2P}{\rho A}} = \sqrt[3]{\frac{2 * 93.6\,W}{1.225\frac{kg}{m^3} * 0.00152m^2}} = 46.5\frac{m}{s}$$

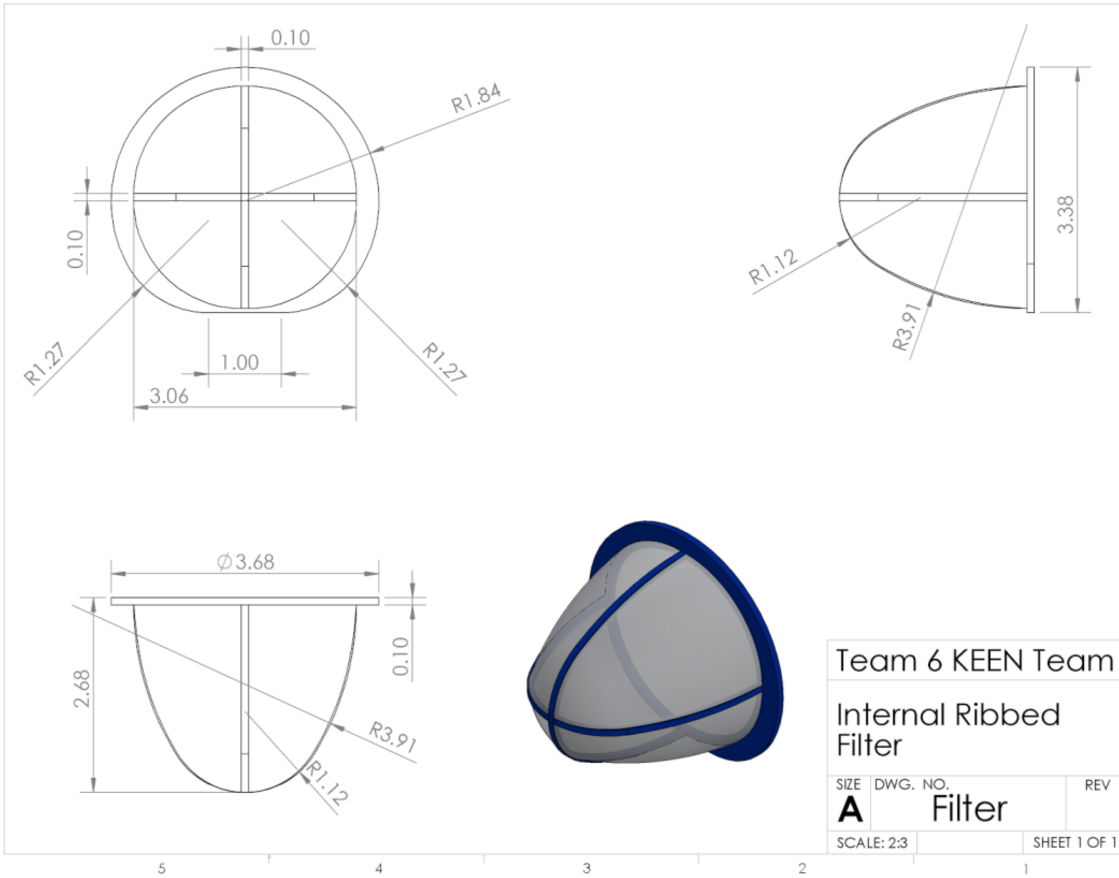
$$Flow\ Rate = V * A = 46.5\frac{m}{s} * 0.00152m^2 = 149.73cfm$$

Appendix D – Detail Drawings

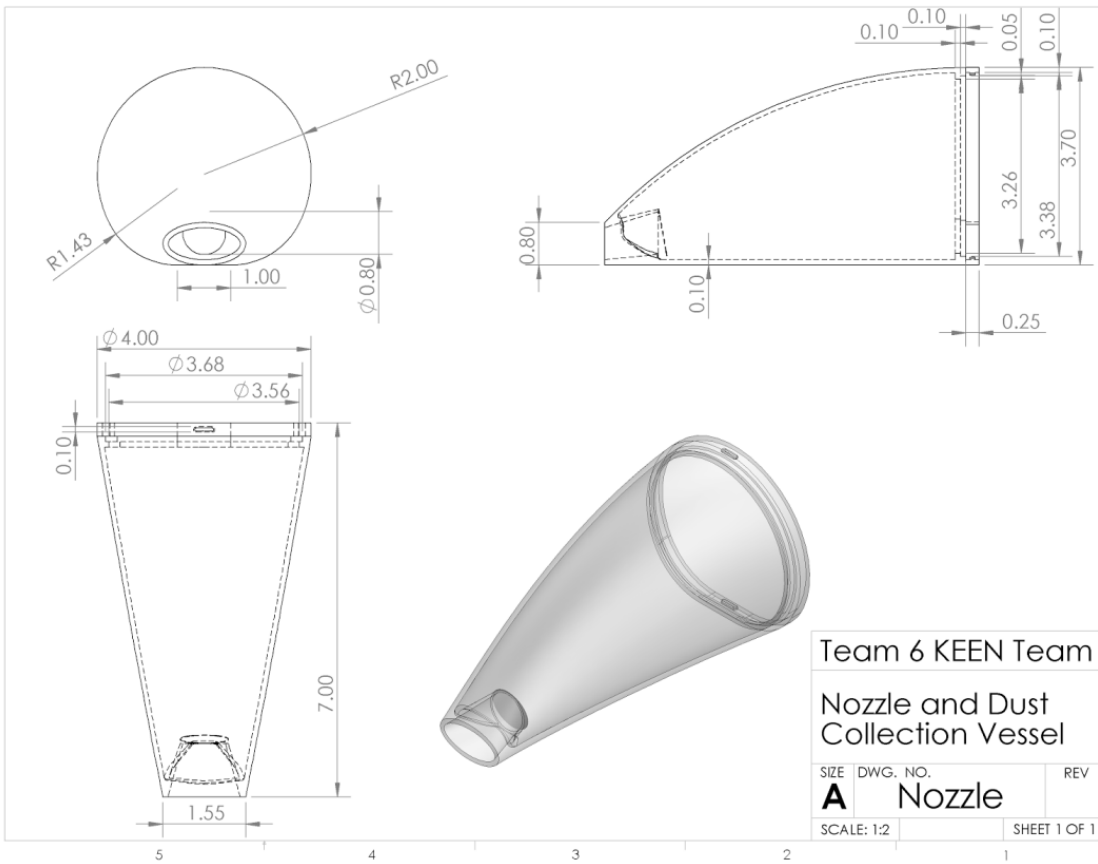
Detail Drawing 1: Fan



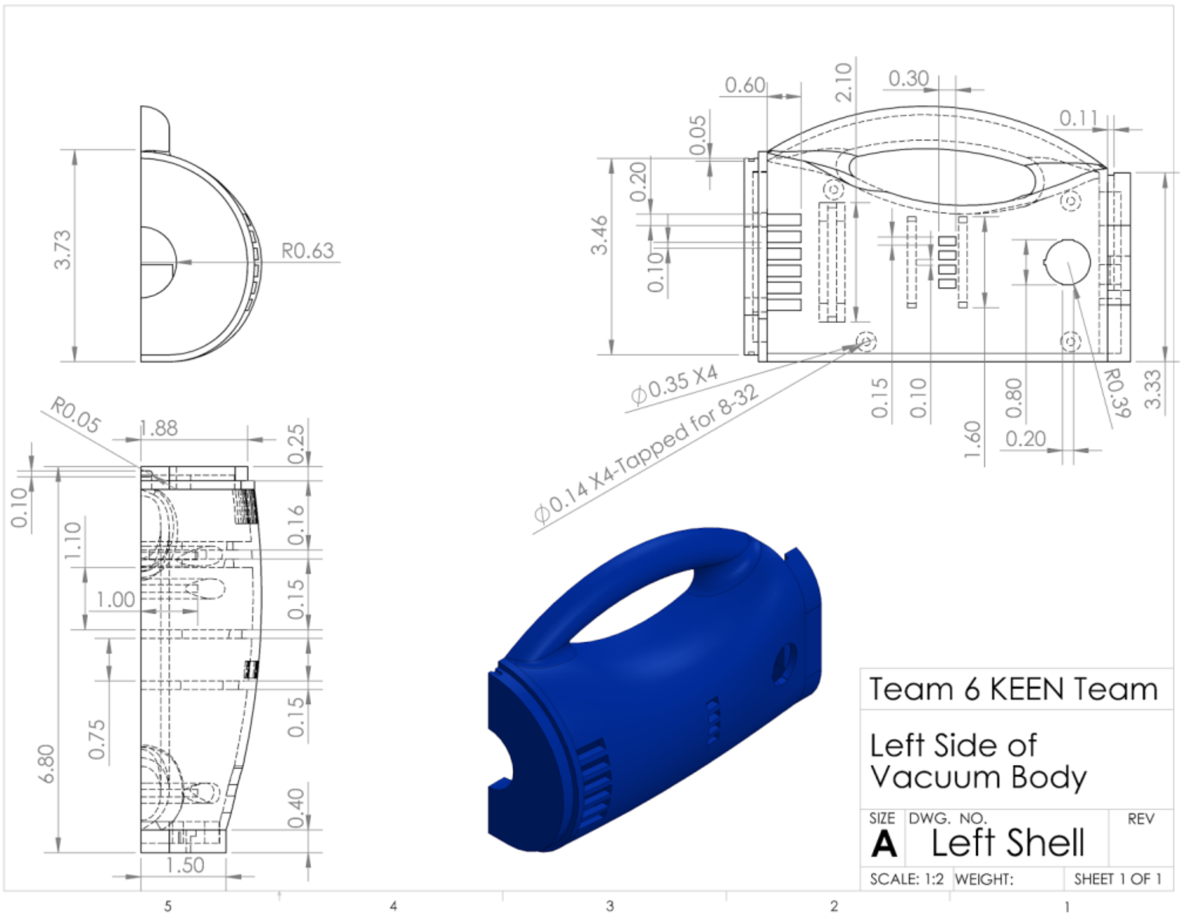
Detail Drawing 2: Filter



Detail Drawing 3: Nozzle



Detail Drawing 4: Housing Left



Detail Drawing 5: Housing Right