To: ACME Tool Company
From: Team Eight (Joe Roberto, Austin Schollenberger, Alan Zimmerman)
Date: September 10, 2015
Title: Cordless Handheld Vacuum Letter of Intent

Dear ACME Tool Company,

Team Eight consists of a team of three Mechanical Engineering students at The Pennsylvania State University: Joe Roberto, Austin Schollenberger, and Alan Zimmerman. We come from unique backgrounds and possess a wide variety of skills and talents that will ensure the innovation of this product is the best. Our goal for this project is to deliver ACME Tool Company a state of the art, handheld cordless vacuum design and prototype. This design will focus directly on the vacuum’s economic potential, aesthetics, ergonomics, safety, and most importantly the performance of the vacuum. We plan to have this accomplished in time for this cordless vacuum to be in stores for the 2016 Holiday season.

We will develop a cordless handheld vacuum that will be easily integrated into ACME’s existing family of power tools. The cordless handheld vacuum eliminates the hassle of a tangled cord and allows it to be used in a wider range of places. Integrating the vacuum into ACME’s existing line of power tools by using the same 18V battery and motor from the product family will significantly cut the manufacturing cost. We strive to create a versatile vacuum that will fulfill all the needs of the everyday consumer. We also wish to develop a strong working relationship with ACME so we may assist them in future projects. The main motivation for ACME to pursue this project is to create a family of products that covers all of the everyday user’s needs. This makes the product family easy for the consumer to use while cutting the cost of manufacturing the product family.

Based on preliminary customer needs the vacuum needs to be powerful, lightweight, a strong and secure collection system, and an intuitive design. In our experience we have found needs that are consistent with our preliminary customer needs. We plan to make this vacuum as versatile as possible to satisfy a wide range of customers. To do this we will meet as many customer needs as possible. Team Eight will continue to study customer needs throughout the duration of this design to help us continue to modify our device as needed. As a team we have creative minds and strong CADD modeling and prototyping skills. Using our creativity and the information collected, we will make an innovative solution that we will be able to accurately model and prototype with ease.

Team Eight is excited to begin this journey with ACME Tool Company. Partnering with an American Company that has been delivering the community with high quality products at competitive prices since 1948 brings us a high level of excitement to this project. ACME Tool Company will benefit greatly from this excitement by being the recipient of an extraordinary product. Together we can change the perception that the ancient broom and dust pan is more trustworthy than a handheld cordless vacuum.
To: ACME Tool Company

From: Team Eight (Joe Roberto, Austin Schollenberger, Alan Zimmerman)

Subject: Customer Needs Memo

Date: September 15, 2015

Dear ACME Tool Company,

Team Eight has been hard at work collecting data from customers. These customer needs have been collected through many interviews from various demographics, which is broken down in the Appendix attached to this document. Using this information collected, Team Eight is preparing to provide ACME Tool Company a cordless handheld vacuum that was designed based on what the customer wants.

Team Eight strived to interview many people from various backgrounds to ensure we received a broad range of data to build on. In doing this we interviewed a wide range of ages. We felt age was an important factor and agreed it would be best to interview college aged people, up to senior citizens. It is safe to assume college aged customers would need a handheld vacuum for different purposes than older adults. By interviewing this age-range of people it will provide us the platform to design a vacuum that interests customers of all ages. Figure 2 in the Appendix also shows that there were significantly more 18-30 aged people interviewed. Team Eight feels this age group offered us more accurate data because they are likely to already own and use handheld vacuums, instead of large expensive floor models.

Interviewing minorities was a priority for Team Eight. Although statistically this product will profit more by focusing solely on the majority population, we wanted to include several minorities in our interviews. The variations in this data did not stray from the majority data, but it still offered us priceless information on different tasks various ethnicities use handheld vacuums for. See Figure 3 in the Appendix for an ethnicity breakdown.

From interviewing both males and females we found their use of vacuums differ. From out in the garage, to the kitchen, to the car, and even in a hair salon, the sex of the user does matter when it comes to what people are using their handheld vacuums for. See Figure 4 in the Appendix for a breakdown of genders interviewed.

During our interviews, a couple reoccurring themes arose. The perception among our interviewees was that handheld cordless vacuums do not clean up as nice as stand-up vacuums or Shop-Vacs because they lack power. This is evident in our data (Figure 5) which provided people want more power. Some would try to use a handheld cordless vacuum only to be disappointed, others would not even attempt to use them and go straight for the bigger vacuums. A majority of the people interviewed were also concerned with the collection compartment. Whether it is too small, leaks dust, or just falls off, the collection compartment was a major point of concern.

Topics were not limited to the lack of power or poor collection compartment design. People were also concerned with the vacuum being lightweight. Most likely the vacuum will be used in hard to reach places, so Team Eight agrees this design features a lightweight vacuum. To go along with lightweight, most would like to see the vacuum be a compact tool. These features will be taken seriously to help curb
the perception of being easier to grab the bigger floor vacuum. If the handheld vacuum isn’t compact or lightweight, why wouldn’t a person just drag out the heavy floor vacuum?

From the data collected we feel comfortable prioritizing the customer needs into six categories. First, the vacuum will be powerful enough to pick up every day messes. Next, the vacuum will allow the user to vacuum longer without cleaning it by having a large storage compartment. Third, the vacuum won’t cause the user any more mess or hassle with a secure collection compartment. Next, the vacuum will be maneuverable with its lightweight design. Fifth, the vacuum will be able to reach in tight spaces with its small design. Lastly, the vacuum will operate at a sound level safe and comfortable to be around.

Figure 1.

The above figure (Figure 1) shows the top six customer needs that were mentioned through the interviews. Our final top six slightly vary from the top six pulled from the interviews. Our third priority of having a secure collection compartment appears on our list because we feel a secure compartment makes a safe vacuum. We also included making the vacuum quiet in our priority list. A quiet vacuum is also safer to operate and safer to be around, as well as more enjoyable to use. However, customers did not feel that these two were relatively important compared to other needs in the design of this handheld cordless vacuum.

Team Eight feels the above data collected from the diversity of people not only helps us design an awesome product, but also incorporates all of ACME Tool Companies core values. The safe, reliable design at an affordable price follows ACME Tool Companies motto. Brainstorming has already begun but we are ready to take this collected data and begin design of the future of handheld vacuum cleaners.

Thank you,

Team Eight

Appendix
List of Customer Needs

1. The vacuum will have high suction power.
2. The vacuum will have a large collection compartment.
3. The vacuum will have a secure collection compartment.
4. The vacuum will be lightweight.
5. The vacuum will be small in overall size.
6. The vacuum will be relatively quiet compared to previous models.
7. The vacuum will have adjustable settings for different surfaces it cleans.
8. The vacuum will be affordable.
9. The vacuum will be operable with one hand.
10. The vacuum will have an attachment nozzle for the user to reach high areas.
11. The vacuum will have an indicator letting the user know the battery life.
12. The vacuum will have a long lasting battery life.
13. The design and operation of the vacuum will be intuitive.
14. The vacuum will have multiple batteries.
15. The vacuum will have a smaller head to get into tight places.
16. The vacuum will not spit out anything it sucks up.
17. The vacuum will be able to be stored in a tight area.
Figure 2. Frequency of Age Ranges

- Frequency of Age Ranges

Figure 3. Frequency of Ethnicities

- Frequency of Ethnicities

Figure 4. Frequency of Ethnicities
Table 1.

<table>
<thead>
<tr>
<th>Interviewee Number</th>
<th>Gender</th>
<th>Age</th>
<th>Ethnicity</th>
<th>Need (s)</th>
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<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>30's</td>
<td>Black</td>
<td>2,3,5</td>
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<tr>
<td>2</td>
<td>F</td>
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<td>White</td>
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<td>3</td>
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Table 2.

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Figure 5.

![Frequency of Top 6 Customer Needs](attachment:image.png)
To: ACME Tool Company

From: Team Eight (Joe Roberto, Austin Schollenberger, Alan Zimmerman)

Subject: Benchmarking Memo

Date: September 24, 2015

Dear ACME Tool Company,

The purpose of this memo is to inform and update you regarding our progress in the benchmarking stage of our research. As a team, we have done extensive research regarding our target market, competitor products, and patents. As you will further learn, a couple advantages that our future product has over its competitors is that it will have much higher suctioning power and will be more compact in size and consequently lighter in weight. Two disadvantages our competitors have over us is that since they have a well-known reputation, they can set their prices much cheaper than we will most likely be able to set our starting prices, and our competitor products seem to have additional features such as the cleaning brush that may make their device more versatile than ours. However, with the information collected, we believe we have a great foundation to build off of and move forward into the design process of our product.

A handheld cordless vacuum is a machine that contains a market of a very wide age range. This product is also used by people from many different backgrounds, ethnicities, and lifestyles. Therefore, the market for this vacuum is very broad. However, since most of our customer needs came from people of college age (18-22 years old), our device will better suit their needs, rather than the needs of a senior citizen or middle aged customers. For example, high suction power is a primary need for college students, whereas lightweight is a need for people that are much older and potentially have weaker bones and prone to injury. However, we will still design our device to fit all 6 of the top customer needs (high suction, large collection compartment, lightweight, small overall size, affordable, and operable with one hand), which will cover a wide range of customer needs from many ages, increasing the value and quality of our product. We understand that college students have a small budget, especially when it comes to household consumer products such as a vacuum. Therefore, we will do our best to design our device with the cheapest, yet effective material we can find and set our profit margin relatively low to spark new interests in our product.

Overall, as mentioned previously, we see our product being most competitive in the college age range since this is where most of our customer needs came from. Additionally, college students live
in tight dorm spaces or small bedrooms where there are frequent small messes that need to be cleaned, increasing their need for a small handheld vacuum.

Throughout our benchmarking process, we researched several different competitor products. The first model is called, “DIRT DEVIL GATOR VACUUM BD10100” (Gator). This model has a “flip open dirt cup for easy emptying,” contains high suction power, and is red and aesthetically pleasing to attract the eyes of college students. Some of its specs include a 10.8 V battery, bagless collection compartment, 10.8 V motor. Some advantages of this product are that it is only 2.75 lbs, making it very easy to use without any soreness. Its “powerful suction” makes it easy and quick to pick up dirt and unwanted messes. However, some of its drawbacks are that it is not wall mountable, reducing its ease of storage in tightly packed dorm room spaces or bedrooms, and it takes 24 hours to charge the battery. This product is competitively priced at $39.99. From previous users of this product, they say it has great suction and maneuvers well in hard to reach areas, but the battery life significantly limits the overall quality.

The second model is called, “Black & Decker CHV1510” (Home Depot). It contains a 15.6 V battery, is bagless with just a clear bowl storage container, which makes it “easy to clean and see”. It weighs 5.438lb making it relatively light but not as light as other competitor products on the market. It has a three stage filter making it less prone to clogging and producing cleaner exhaust. It can also be stored horizontally, vertically, or wall mounted for convenience. Its rotating and slim nozzle along with a vide mouth help it collect virtually all dirt and debris, and it is priced at just $50.

The third model is called, “Shark SV780” (Walmart). It has an 18V battery with and indicator to show charge. It has an easy to empty dust cup and a removable and washable filter. It is relatively lightweight at 5.179 lb. One stand-out feature is its detachable motorized brush for hard to reach messes and small spot messes that college students frequently make. It has strong suction that doesn’t dwindle over battery charge, and its handle has an ergonomic design, reducing the strain on its users’ wrists. It is

In addition to competitor product searching, we also did extensive research on existing patents of cordless hand held vacuums. One of which is filed as “US Patent 8549704 B2,” and it is a simple yet effective hand held cordless vacuum. This patent is authored by Michael A. Milligan, and it expires in 2033. The patent which has since been abandoned features a collection compartment in front of the vacuum on-off switch, and was an original assignee of Black and Decker. The focus point of their design was adding a HEPA filter in the internal hose to collect the smallest of particles, preventing them to reach the motor or electrical components. The aesthetics of the vacuum leaves much to be desired.
Another interesting patent we researched was “US Patent 5025529 A.” This patent is authored by David R. Hult, and it expired in 2011. It features a design that resembles the Black and Decker patent described above. What separates this vacuum from others is its attachments. The vacuum can accommodate wet-vacuuming by an add-on squeegee. The squeegee has a wiper blade which lifts as much water as possible making it easier for the vacuum to collect it. This vacuum also allows the user to put various battery combinations in and will still be operable. This patent was filed in 1989 and is now “US Patent 4920608.”

A trend among patents researched was that most vacuums of this nature all look the same. The two patents listed above, as well as “US Patent 4011624,” authored by Mark Anton Proett (expired in 1997) have the cone/collection compartment in front of the on/off switch. These designs make the vacuum compact by doubling the nozzle as a collection compartment. Although surly compact, this design leaves a small opening for the user’s hand which may become uncomfortable.

Considering all the information we have collected regarding target market area, competitor products, and patents, we believe our future product will be successful. Directing our attention towards the needs of college students is where the most popular demands are for a cordless handheld vacuum based on our findings. We have also established a great foundation, knowing where our product will lie in comparison to its competitors. Understanding the advantages and disadvantages will guide us to the proper design of our device. Similarly, having a background knowledge on existing patents makes us of what other designers and manufactures currently working on, giving us plentiful ideas for further design solutions for our device. Research of what already exists is a vital component of designing a new product. Our research has been extensive and will continue as this project moves forward.
With what we have found we have set the groundwork for what ACME Tool Company and Team Eight is trying to accomplish. Pairing this product research with our customer needs research is unveiling the opportunity for great innovation.

Note: See Appendix for the QFD.

Sincerely,

Team Eight
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<tr>
<th>Needs</th>
<th>powerful motor</th>
<th>size of collection compartment</th>
<th>failure ratio of compartment lock</th>
<th>total weight</th>
<th>overall dimension</th>
<th>Sound Level</th>
<th>number of settings</th>
<th>number of attachments</th>
<th>battery life</th>
<th>battery indicator light</th>
<th>width of vacuum head</th>
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<tbody>
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<td>1. high suction power</td>
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<td>3. secure collection compartment</td>
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<td>5. small overall size</td>
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<td>6. produce minimal noise</td>
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<td>7. different settings for different surface types</td>
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<td>8. affordable</td>
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<td>9. be able to be used with one hand</td>
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<td>10. come with an attachment hose/nozzle</td>
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<td>11. long battery life</td>
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<td>12. battery will indicate charge</td>
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<td>13. will have easy to use controls</td>
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<td>15. will not eject any debris</td>
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<td>16. small head to reach tight places</td>
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<td>17. compact for easy storage</td>
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References


Dear ACME Tool Company,

Team Eight has compiled 12 specifications for this vacuum that were derived from customer needs. We have since weighted these 12 specifications for importance. Through this weighting process Team Eight concluded the following are the key specifications for this vacuum. The first is a collection compartment that will hold 50 square inches of debris, this allows for long breaks between emptying debris. The vacuum will be no more than 6 inches wide by 12 inches tall and 6 inches deep, which keeps the vacuum compact for tight spaces. The vacuum will weigh less than 6 pounds, which makes the vacuum comfortable to use for long durations of time. The vacuum will produce less than 70dB of noise, which prevents any hearing damage to the user or bystanders. The vacuum will have power of at least 15 watts, making sure to pick up every particle. This memo will describe the Black Box method we used to break down and simplify the overall system of the vacuum, the specifications, and how we weighted them.

Using the Black Box method, it is possible to break down the overall system into its basic inputs and outputs in relation to its overall function. This can also be further broken down into many different sub-functions, which can be classified as Sub-Functions and Auxiliary Functions.

Referring to the generic black box (Fig. 1), the overall function, which is in the black box, is to vacuum surfaces. To the left of the black box are inputs broken down by color into energy (yellow and green), materials (blue), and signals (red). To the right of the black box are the outputs, whose colors also correspond to the input colors, with the exception of black indicating an “other” output that does not fall into one of the three categories previously mentioned. The overall message of this image is that once the “On Button” is pushed, electricity is fed into the vacuum, along with translational energy from movement of the arms and hands of the user. Dirt is sucked into the vacuum, and its output are some heat, and of course, cleanliness, with the “Off Button” being the final signal to power the machine down.

Referring to the broken down black box (Fig. 2), the overall function is the same, but there are now 6 primary sub-functions and two auxiliary functions. Once the vacuum is turned on, electrical energy spins the motor, which also runs the fan. The spinning of the motor, and consequently the fan, creates a pressure difference, which causes the dirt to be sucked up and stored in the collection compartment. Due to the intake of air when sucking up the dirt, there is also a small discharge of air as well. At the end, just like in Figure 1, the vacuum is turned off, and all of these sub-function help achieve the overlying function: clean surfaces (to vacuum).

We further broke down the specifications using an AHP method. Specifications were derived from our customer needs but needed to be weighted for importance. Using the 6 specifications (power, storage size, security, weight, small sized, quiet) we made a table (Fig. 3) that compared each spec head-to-head with the others. Team Eight worked collectively while deciding what weight one spec carried over
another. We discussed and took account for data that was collected through benchmarking other products and customer needs. In doing this we found that power is the most important at 44.5%. Second most important is storage size at 22.6%. The next most important spec is weight at 12.7%, while fourth is being compact at 9.6%. The fifth most important spec is a quiet vacuum at 6%. Lastly is the compartment security at 4.6%. All of these weighted percentages add up to 100%.

With these weights in mind we will begin our first round of design concepts. For this first round each team member will create 5 design concepts (15 total). We will then weigh all 15 of these concepts using a concept screening matrix. For this concept screening matrix we will choose a cookie cutter vacuum for a reference. The matrix will include the rows of specifications: power, compartment size, weight, noise, cost, settings, secure, battery life indicator, attachments, and size. For each design concept we will choose if its specific specification is worse, better, or the same as the reference vacuum, by scoring it a “-“, “0”, or a “+”, respectively. The 3 designs with the highest net score will be chosen for further design.

Fig. 6 in the appendix shows a breakdown of the black box and specifications that have been given a numerical value. The value placed for each specification was derived by researching competition, implementing customer needs, and values Team Eight felt would make our vacuum surpass anything else on the market. These values are subject to tweaks, but our goal are to realize all specifications as that will ensure a quality product.

Using a dynamometer we were able to obtain great information regarding the motor we are going to be using in the vacuum. The dynamometer supplied a torque to the motor, and rpm, voltage, and amperage measurements were recorded (Fig. 4) with the drill running at full throttle. We began with 0 torque, then slowly increased in torque until we reached close to 9.5 A, which happened to fall at 625 oz.-in. Staying below 10A assured the motor and battery were not damaged during this testing. We took 8 readings at various torques, enough for us to derive rpm’s, efficiency, and power versus torque.

Data from a partnering company, Team 6, was derived using the same process described above. We used their data due to some technical errors involving misreadings of the voltmeter (Fig. 4) and plotted current vs. torque. As you can see in Fig. 5 the plot produced is nearly linear, as the torque increased so did the amps. We also used Team 6’s data to plot power out vs. torque. This graph also resembles a linear plot, as the torque rises so does the power.

Six teams, including our team, tested these motors on the dynamometer. Using the data found we were all able to derive the efficiency of the motor. The plot of all six teams is below in Fig. 5. By averaging all the plots we found the efficiency of the motor to be roughly 0.045% when the drill is running at full throttle. Because we are unable to modify the motor in any way, this efficiency will be nearly identical to the efficiency of our vacuum.

Team Eight is organizing and prioritizing the design of this vacuum by means of weighting, use of a black box, and data collected. By approaching the design from various angles, using multiple tools, the vacuum design is quickly taking shape. Our next step is taking these theoretical designs and developing prototypes from them.

Thank you,

Team Eight
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**Fig. 4**

---

| RPM  | Load Torque (oz-in) | Input Voltage (Volt) | Input Current (Amp) |              |              |              |              |              |              |              |              |
|------|---------------------|----------------------|---------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 650  | 0                   | 0.15                 | 3.6                 |              |              |              |              |              |              |              |
| 685  | 25                  | 0.10                 | 3.1                 |              |              |              |              |              |              |              |
| 655  | 50                  | 0.10                 | 3.5                 |              |              |              |              |              |              |              |
| 760  | 75                  | 0.31                 | 3.4                 |              |              |              |              |              |              |              |
| 750  | 150                 | 0.31                 | 3.9                 |              |              |              |              |              |              |              |
| 685  | 250                 | 0.14                 | 6.0                 |              |              |              |              |              |              |              |
| 585  | 375                 | 0.17                 | 8.0                 |              |              |              |              |              |              |              |
| 505  | 625                 | 0.23                 | 9.5                 |              |              |              |              |              |              |              |

**Team Eight's Data**

---

| RPM  | Torque (oz-in) | Voltage | Ampereage |              |              |              |              |              |              |              |              |
|------|----------------|---------|-----------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 605  | 150            | 18.2    | 8.5       |              |              |              |              |              |              |              |
| 575  | 125            | 14.2    | 7.2       |              |              |              |              |              |              |              |
| 605  | 100            | 14.9    | 6.32      |              |              |              |              |              |              |              |
| 792  | 76             | 13.68   | 5.3       |              |              |              |              |              |              |              |
| 793  | 50             | 16.55   | 4.4       |              |              |              |              |              |              |              |
| 818  | 25             | 16.85   | 3.5       |              |              |              |              |              |              |              |
| 850  | 0              | 16.6    | 2.4       |              |              |              |              |              |              |              |

**Derived Data From Team 6**

---

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**Load Torque (lb-ft)**

- 0.781
- 0.651
- 0.521
- 0.391
- 0.260
- 0.130
- 0.000

**Fig. 5**
Fig. 6
Key Specifications
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<td>Vacuum will produce less than 70 db of noise</td>
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<td>Will cost no more than $60</td>
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<td>Will have between 2 and 4 surface settings</td>
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<td>The collection department lock will fail no more than 1% of the time</td>
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<td>Battery will last at least 1 hr</td>
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<td>Battery life indicator will turn on at 25%</td>
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<td>Will have between 2 and 5 attachments</td>
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<td>Vacuum cleaner head will be at least 4 in across</td>
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<tr>
<td>Vacuum will be no more than 6 in wide by 12 in tall by 6 in deep</td>
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To: ACME Tool Company

From: Team Eight (Joe Roberto, Austin Schollenberger, Alan Zimmerman)

Date: October 20, 2015

Title: Concept Generation & Selection Memo

Dear ACME Tool Company,

The purpose of this memo is to inform ACME Tool Company that we have selected one design concept through a number of different procedures that we will further discuss in detail below.

Overall we began individually generating many ideas, 15 total to be exact, of different designs for a handheld cordless vacuum. With each idea, a drawing and a brief explanation was included. We then generated a concept screening matrix and narrowed our design ideas down to five. These five designs were physically built or drawn and presented to random people throughout the Penn State campus. With this feedback, we again narrowed our design ideas down to three, and made an exploded drawing and a sub-system drawing for each one. From these three drawings and the physical prototypes in front of us, we generated a concept selection matrix, using the AHP method to determine our weights. Each of the three ideas were scored and the winning design was concept J, of which we will be constructing an alpha prototype shortly.

To create our concepts each group member used our benchmarking data, customer needs, and design specifications to generate 5 ideas each. No brainstorming or brainswarming was used. We tried to incorporate the core customer needs while also making it aesthetically and ergonomically pleasing. In the process we put out our ideas and team members gave feedback to help adjust and improve different concepts. We then came together and tried to narrow down our designs to just 5.

To downselect our concepts we rated them on key design specifications. We used a rating system of 0, +, and -, while comparing them to a reference vacuum already on the market. This reference scored a 0 in every category (our design metrics). So if a concept received a zero it was equal in that category to the reference, a plus was better, and a minus was worse. Once each concept was scored in these categories we added all the +, -, and zeros together to get a final score. From these final scores we took the five concepts with the highest scores to continue with. We then took those five concepts and drew a more detailed drawing of the concept design. Below is a detailed description of the five concepts that scored the highest in the concept screening matrix.

Concept B: This design received the second highest score during concept screening. The model was very crude but emphasized the key features of the concept (Figure 1). This design received a mix review because although the handle and overall design of the vacuum was liked by all who tested it, none of the them liked how boxy/bulky this concept was. Even though this model was very rough and the real vacuum wouldn’t be nearly as bulky, this feedback shows that the consumer is looking for something very compact. This confirmed a variable we found in customer feedback that consumers want a compact vacuum.
Concept G received the best score of the 15 concepts screened in the concept screening matrix. The concept was a compact body that contained the storage, motor, pump, and battery. It was to be held using a semicircular handle attached to the back. It also had a long hose/nozzle on the end and small head to help reach those tight hard to reach places (figure 2). Customer feedback on this concept was mostly positive. They overall flow and ergonomics of the design were well received. The customers liked the longer hose/nozzle that would allow them to get into hard to reach places without too much effort. However there were concerns that when it would be too long and possibly too heavy once it was fully finished. There was also some concern that the handle may be uncomfortable if used for a long period of time.

Figure 2: Concept G (Rough sketch and explanation on the left and the physical model on the right).
Concept J: This design received the third highest score in the concept screening matrix. This crude model was a sufficient representation of its true exterior design and function. Most customer feedback centered around one positive and one negative comment. Users like how the design includes two collection barrels for longer lasting use. However, they also argued that the area of the intake may be too large to provide enough suction to pick up dirt. The customer feedback for this design confirmed that users prioritize a powerful suction and any design feature that maximized the time used in-between emptying the collection compartment.

![Concept J (Rough sketch and explanation on the left and the physical model on the right).](image)

Concept L: This design also received the third highest score, tied with concept J. Although it was only a drawing, it was sufficient to obtain valuable feedback. Most customers were attracted to the spherical collection compartment, as this is a rather taboo design. They also liked the compact size. One criticism was that it would be tough to tell if the handle is placed in the proper location to balance the weight distribution since we did not have a real alpha prototype with similar materials that we would use for the final product. Similarly, others also argued that the intake might be too large to provide sufficient suction. Contrary to our customer needs, the people we interviewed seemed to value aesthetics more than we thought.
Concept M: This design received the fifth highest score in the concept screening matrix. Customers enjoyed the look of this vacuum. They felt from the drawing that it looks like a cool vase when standing upright, and that it could also be conveniently hung on a hook from its two handles. That was about the only good feedback received from this model. Some of the more critical feedback was that it would be awkward to use, poor geometry for getting into corners, and it would fatigue the user quickly.

These five designs were the ones we modeled for customer feedback, and they were the top scoring ones from the concept screening matrix (Figure M - Appendix). These were very crude models as shown above, non-functioning, and made to get the basic idea of its exterior design and how the vacuum would operate, given its rough geometry. However, two of the five designs were detailed drawings rather than pre-alpha prototypes, and this was solely due to time constraints. The purpose of the models was to gain valuable customer feedback to help us further eliminate two of the five concept models. Each member of Team Eight took a design to the streets to collect feedback from random people. Below is each of the design models, as well as some key feedback each design received. We agreed to eliminate concepts L and M because they did not receive as much positive feedback as did the other three design concepts. Maybe this could have been due to the fact that these were the two concepts that were drawings. Regardless, most customers agreed that those two concepts were their least favorite when asked. However, since we have tentative final designs, we will consider the positive remarks regarding these two concepts such as the handles that can be used for hooks and the aesthetically pleasing spherical collection compartment when we further tweak our final design.

The three selected designs can be broken down into sub-systems. Each design focuses on the sub-systems we found most important during our customer needs study and benchmarking study. Because
the battery life cannot be altered to keep the parts the same and reduce manufacturing cost, each design tackles other sub-systems differently. Power was not considered as much due to the same reason, however power can be slightly altered based on the size and geometry of our fan/impeller.

Design B: This design is broken into simple sub-systems. It contains the battery, switch, motor, fan/blower, collection compartment, vent, and the filter. The intake of this design is to the far right. This is where the debris will be sucked up into. The debris will then fall into the collection compartment. The filter comes between the fan and collection compartment protecting the components from any debris. The vents are above the fan, which is directly attached to the motor. The switch on this design is in fact a trigger switch. We felt this would save battery life as the user will only suppress the trigger when they were ready to collect. The battery is located in the back to counter-balance the drill and keep it out of the way.

Design G: The sub-systems of concept G are clearly show in the left side of Figure 7. The first sub-system of this design is the intake. It is a small head that faces down attached to a long nozzle. This gave ample reach so the user doesn’t have to strain themselves too much to clean everything. The second sub-system is storage which comes right behind the intake. It is a large removable container to store a large amount of debris. Since it is removable it is easy to clean and empty. The filter comes next and is in front of the circuit sub-system so no debris get in and damage any important parts. The circuit consists of the battery, motor, and on/off switch. When the on/off switch is pushed the battery powers up the motor.
spinning the attached shaft. The shaft is then attached to a pump that pulls air in from the intake. The air is mixed with debris that are stopped by the filter and then left in the storage compartment while the air passes through. Once the air exits the pump it continues to go up and out the exhaust ports on the top of the vacuum. The right side of Figure 7 shows how all of these sub-systems would fit together to make the complete vacuum.

Design J: This concept was broken down into four sub-systems: intake, circuit, filter, and storage. The intake system is simply the head of the vacuum labeled, “intake” in Figure 8. In the drawing, it is clear that the direction of intake of debris is from the left to the right. This suction power is created through a pressure difference caused by the circuit system. This system is composed of the motor, fan, and battery (not labeled to avoid clutter), which are shown to the right of the intake head. The motor spins at a fast rate, which is connected to the fan, causing the fan to spin at the same rotational velocity. Due to the angle of the fan blades and its rotational velocity, they together create a pressure difference beteen the intake (low pressure) and behind the fan (high pressure). Behind the fan and motor is a battery, which is connected to the motor, giving it energy to turn rapidly. These three components (motor, fan, battery) are inside the hull of the vacuum, separate from the collection and filter system. On the left and right of the hull are the collection compartments, which both act as the storage system. There are two cylindrical barrels that act as the collection compartment, and entrance to them are connected to the back end of the vacuum head, where the dirt and debris is sucked. Dirt is collected, along with air and “pushed” to the end of the barrel (towards the right in the figure below) where the filter is. Please note that it came to light that the location of the filter in this picture would not be feasible because it is after the impeller/fan (the exploded solid works model has the new filter location before the fan to eliminate an damage to the fan caused by incoming debris particles). The filter system is composed of the filter, the end (farthest right) side of the hull, and the vents. There are two filters, each one being connected to the inside and outside of each collection barrel and also to the empty space in the back of the hull. As dirt and air flow to the end of the collection barrel, dirt hits the filter and remains inside the compartments, while the air passes through the filter and into the empty space of the hull. Once the air is in this space, it is free to exit the vents (and into the atmosphere), which are cut into the top part of the back end of the hull, as shown in Figure 8.
The basis of our weights for the concept selection matrix (Figure 9) was determined using the AHP method. To do this, we created a matrix of the six sub-functions running in both rows and columns, blacking out the diagonals (Fig N - Appendix). Each sub-function in the column was compared to each sub-function in the row using numbers 1-9 to signify relative importance. For example, referring to the figure, in the third column and second row, we concluded that security is 1/3 as important as the collection compartment size. The total score for each sub-function in each row was added up and divided by the sum of all total scores to determine the final weights. We took concepts B, G, and J and compared them side by side. Our judgements were based on our six major subfunctions of Power (15W), Collection Size (50in^3), Secure (<1% failure), Weight (< 6lbs.), Compact (6x12x6 in.), and Noise (< 70db). Each vacuum received a score from 0 to 5 based on how we felt they compared to our subfunction specifications and the other models. After they were assigned a number from 0-5 for each sub-function, we then weighted those numbers using the weights we derived from the AHP method. The total scores after the weighting was applied were then added up and the one with the highest score was the design we chose to move forward with. That design happened to be design J.

![Figure 8: Detailed drawing of Concept J](image)

![Figure 9: Concept Selection Matrix](image)

It is obvious that the final score was very close between design concept G and design concept J.
Although we will be integrating some parts of both design B and design G into our final product, we felt design J gave us the best design going forward to achieve the vacuum that all of our data has pointed to. As you can see from figure 10 below, Design Concept J features two cylindrical collection compartments. The handle is located at the top of the vacuum in the center of mass to perfectly balance the vacuum in the user's hand allowing for hours of vacuuming. The on/off switch is also located on this handle. Internally the design is very simple. The battery plugs into the back of the vacuum. The power from this battery runs the motor which is located internally roughly under where the handle is. The motor spins a fan causing a pressure difference that allows the vacuum to suck up debris. There is a filter in between the nozzle and fan to keep it from getting damaged from debris. The suction cone is large enough to pick up larger pieces of debris without getting clogged. All together the vacuum is an aesthetically pleasing machine that is different from models on the market today.

Overall, Team Eight is content with our findings. We properly downselected from our 15 ideas to five functional concepts. We confidently further downselected from five to three concepts based on customer feedback and our own judgments. From these three ideas we selected concept J to be the one that we will move forward with and be the blueprints for our first alpha prototype. We are also happy that we caught the mistake regarding the location of the filter early on, before we began prototyping. The Solid Works model in Figure 10 shows the true design as of now. We will continue receiving customer feedback and make any adjustments to our design as necessary. We are excited with the direction our studies are taking this product and look forward to presenting you our prototype.

Thank you,

Team Eight
Appendix
**Idea Generation**

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- handles for grip
- battery life indicator
- long reach

*Figure A: Idea Sheet #1*
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

![Idea Drawing](image)

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- long extension
- big storage
- battery indicator
- surface settings

*Figure B: Idea Sheet #2*
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- Small
- Short handle
- Multiple settings
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- Attachment for more usability
- Ergonomic handle
- Storage in front with latch
- Battery life indicator

Figure D: Idea Sheet #4
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- box multiple surface settings
- grip handle
- battery life indicator
- longer handle for reach
- large storage in the back
Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- Long nozzle for easy to reach
- Grip warm supports for more versatile use. Rest with safe
- Solution component behind nozzle.
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

![Diagram of a backpack cleaning device with the label 'Sack-Vac'.]

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- Light backpack model
- eases for long cleaning sessions
- quiet without sound insulation
- attachments for sweeping or nozzle
- has bladder bags for dirt, just take out feel

Figure G: Idea Sheet #7
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

Grip like drill but nozzle is on top.
Latching switch.
Collection compartment, square not an odd shape, latchetsketch directly attachment for reaching under couches/dairy floors about
Killing back.
Battery indicator.
Simple design - cheap to manufacturer.
Idea Generation

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- Uses mostly drill components.
- One long/sturdy/narrow nozzle w/LED on end, activates when trigger is pulled to see in dark areas.
- Collection compartment in back to balance drill in hand.

Figure I: Idea Sheet #9
Your Name: ____________________________  Problem #: ______  Idea #: ______

Idea Drawing: Sketch your solution idea in the box below.

Idea Description: Describe the solution idea. How does it work? What are the features, mechanisms, and details?

- Utilizes much of the drill body - the chuck & gears.
- Plastic body would be insulated to lower noise levels.
- Collet clamping mechanism or tap for easy changing. Can tell when full.
- Adjustable handles with 8 more power design for around 2-3.
- Can fan wear in inverse to blow it cooled.
- Battery life indicator.
Figure K: Idea Sheet #11-12
Figure L: Idea Sheet #13-15

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Figure M: Concept Screening Matrix

- [x] Concept Modeled
- [x] Concept Exploded, NOT Modeled
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<th>Storage Size</th>
<th>Security</th>
<th>Weight</th>
<th>Small Size</th>
<th>Quiet</th>
<th>Total</th>
<th>Weighting</th>
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<td>0.096</td>
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<td>1/4</td>
<td>2</td>
<td>1/3</td>
<td>1/2</td>
<td>3.25</td>
<td></td>
<td>0.060</td>
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</table>

**Figure N: AHP Matrix**
To: ACME Tool Company

From: Team Eight (Joe Roberto, Austin Schollenberger, Alan Zimmerman)

Subject: Theoretical Analysis Memo

Date: November 3, 2015

The purpose of this memo is to inform ACME Tool Company of our technical analysis research. We have been working hard to find the right pump to use in this vacuum for optimal performance. Throughout this analysis we have determined the best pump for our design, how changes of various parameters for the pump and vacuum affect them, and the overall performance of the pump we are deciding to use.

Since flow rate remains constant throughout the system, varying the cross sectional area is what dictates the velocity of particles. The smaller the cross sectional area, the higher the velocity and vice versa. Therefore we can manipulate cross sectional areas in order to vary the velocity. Preferably, the intake would have a smaller cross sectional area than downstream in order to provide better suction.

By researching top vacuums currently on the market we found that our vacuum needs to have between 15in.-30in. of static pressure and between 40cfm-60cfm of flow rate. We derived the rpm of the ACME drill motor without the gears to be 4500rpm using McMaster-Carr. On their website, we found a motor of similar dimensions and properties. However, they did not have the exact motor voltage that we have, so we interpolated and arrived at 4500 rpm. After collecting this information we then looked up a current fan on the market, the DC250-2B50 from Continental Fans. We chose this fan because it runs off a DC motor, and is very efficient. This is a highly versatile fan that is quiet and can be run at a wide range of temperatures. Continental Fans provided great data for this fan allowing us to scale it to the sizes we need using the Affinity Laws seen in Figure 1.

The Affinity Laws show how various changes in parameters affects the vacuum performance. For example, referring to the first equation in Figure 1, if the rpm is decreased, then so too is the flow rate, which leads to less suction. However, if the diameter of the turbine increases, so too does the flow rate.

Using the first Affinity equation (Figure 2) we solved our fan’s flow rate. The 37.5cfm is slightly lower than the recommended range but we can bring that value up by the geometry of our fan. The ratio of cfm of our fan with respect to the reference fan was then found to be 0.054.

\[
\frac{Q_b}{Q_A} = \left( \frac{\omega_B}{\omega_A} \right)^{\frac{3}{2}} \left( \frac{D_B}{D_A} \right)^3
\]

\[
\frac{bhp_b}{bhp_A} = \left( \frac{\omega_B}{\omega_A} \right)^{\frac{3}{2}} \left( \frac{D_B}{D_A} \right)^3
\]

\[
\frac{H_b}{H_A} = \left( \frac{\omega_B}{\omega_A} \right)^{\frac{3}{2}} \left( \frac{D_B}{D_A} \right)^3
\]

\[
\frac{V_b}{V_A} = \left( \frac{\omega_B}{\omega_A} \right)^{\frac{3}{2}} \left( \frac{D_B}{D_A} \right)^3
\]

Figure 5: Affinity Laws

\[
Q_b = Q_A \left( \frac{\omega_B}{\omega_A} \right)^{\frac{3}{2}} \left( \frac{D_B}{D_A} \right)^3
\]

\[
= 4.87 \left( \frac{\omega_B}{\omega_A} \right)^{\frac{3}{2}} \left( \frac{D_B}{D_A} \right)^3
\]

\[
= 37.5 \text{ cfm}
\]

Figure 6: The first Affinity equation used to solve our fan’s flow rate
Similarly, we then found the head pressure ratio of the fans to be 0.34 by using the second Affinity equation (Figure 3).

\[
\frac{H_B}{H_A} = \left(\frac{\omega_B}{\omega_A}\right)^2 \left(\frac{D_B}{D_A}\right)^{2.50} = \left(\frac{60 \text{ rps}}{23 \text{ rps}}\right)^2 \left(\frac{3}{4.5}\right)^{2.50} = 0.34
\]

*Figure 7: The second Affinity equation used to solve our fan’s head pressure*

We then used these ratios, along with performance curves of the reference fan, to derive performance curves of our fan. We did this by multiplying their head pressure values (y-axis) by our ratio of 0.34, and multiplying their flow rate values (x-axis) by our ratio of 0.054. This gave us a performance plot for our vacuum, shown in Figure 4.

![Performance Curve](image)

*Figure 4: Performance curves for our fan with varying fan diameters*

Calculating the efficiency of our fan is necessary as these values will dictate the marketability of our product. Assuming we use a 3.5 in. diameter fan, 0.25 in (60 Pa) pressure head, and 60 CFM (0.0283 m³/s), 150 oz-in (1.06 Nm) of torque and 550 rpm, our efficiency would be calculated as follows:

\[
\text{Work Out} = \rho g Q H = 1.225 \times 9.81 \times 60 \times 0.0283 = 20.41 \text{ W}
\]
\[
\text{Work In} = T\omega = 23 \times (9.167) \text{ rps} \times 1.06 \text{ Nm} = 223.5 \text{ W}
\]

Dividing Work Out by Work In, we get an efficiency of 9.13%. The rpm and torque were found using our graphs provided in design specification memo, and we chose the rpm that equated to the most efficiency, and the corresponding torque.
We chose to design our fan blades using our performance curves. We know that in order to achieve a desired flow rate, we can determine the pressure head based on the graph. From these two values, we can apply the Affinity Laws to determine what our required fan diameter would have to be at a designated RPM in order to satisfy these requirements. Our turbine blades will be a typical centrifugal fan because these types of fans are easier to direct the exhaust to the vents. Referring to Figure 5, the air flows into the dome of the fan, causing a smoother fluid flow into the blades, which guide the air into the multiple vents (not pictured in the image) that would be around the circumference of the housing directly above the fan. For now, we plan to use a 2.875 in. diameter fan blade to use the least amount of material and consequently lowest costs. This small diameter of a fan should still provide sufficient suction. However, we will continue to test this product and determine if it is obtaining enough suction to pick up debris such as dry rice, and we will modify our turbine geometry as necessary.

As always, thank you for your time.

Team Eight
Dear ACME Tool Company,

Team Eight is pleased to present to you our research results for the manufacturing decisions of our vacuum. In this memo we will discuss the components, the proposed materials, the cost, and economic justification for the handheld vacuum. With 12 major components and using various materials such as ABS PC and carbon steel, keeping the manufacturing cost of this device low was a great challenge. In this memo we will describe to you how we overcame this challenge.

Our vacuum currently has 9 unique parts. That number may change as we enter the final weeks due to minor tweaking of the design. The parts are: casing, nozzle, end caps, handle, filter, battery, motor, fan, and discharge flap. The battery and motor are provided by ACME Tool Company and Team Eight will have no input on the manufacturing of those components. The remaining 7 parts were heavily researched and we found the components should be made from the following materials:

**Casing**: The casing should be made from plastic. This is the largest part on this vacuum and is split into two symmetric halves to ease the assembly process. By manufacturing the casing from plastic this will keep the weight of the casing low in comparison with other materials. The plastic casing will also have a low cost to produce with the process of thermoplastic injection molding (Figure 1). The plastic casing will also be strong enough to carry the load of the vacuum.

**Nozzle**: The nozzle will take the bulk of the abuse but it is still the best option to make from plastic. Like the casing, manufacturing this part from thermoplastic injection molding will keep the costs low. Also, with the process of injection molding we can design the molds for any thickness desirable, giving us the flexibility to make this part as strong as necessary.

![Figure 8: How the injection molding process works](image-url)
Fan Backing, Fan Shroud, End Caps: These parts are essential for the safety of the vacuum and to guarantee good suction. They need to be sturdy to ensure that no debris shoots out, potentially harming people. Staying consistent with the above, these parts will be made from plastic. The strength of the plastic is sufficient to keep contents inside the vacuum, while also being light weight. These pieces will not need to be injection molded, as they are simple discs. These parts will be made by laser cutting the discs from a sheet of plastic, keeping costs low.

Handle: The handle is a custom part Team Eight designed to distribute the weight of the vacuum. Because of this the handles must be made from plastic and manufactured using injection molding to again keep costs to a minimum. Using plastic will keep the handles strong enough while offering lighter weight than other materials, minimizing the risk of back, arm, and wrist pain of the users.

Filter: The filters will be an off-the-shelf component (COTS) for the vacuum. They will be made from wire mesh and purchased via competitive contract. Although it will cost money to buy filters for each vacuum produced, the cost of filters is relatively low compared to the other components. This will leave us with a very little to negligible decrease in profit margin. However, it also saves the employees time to make these wire meshes, which also contributes to a decrease in the labor expenses. Metal wire is the material chosen for the filter because in addition to being a standard, it also serves as great protection for the fan.

Fan: Since this component of the fan is essentially the main component (aside from the motor) that performs the vacuum’s function, we chose steel because it is very rigid, providing structural integrity so that the fan can withstand any unexpected stress that may occur or if the filter fails. This will be more expensive than other materials but will ensure durability and precision. The fan will be machined from carbon steel using green sand molding, which is a relatively inexpensive molding procedure because sand is very cheap and it can also be recycled for future molding use.

Screws: The vacuum will need at the least 4 screws to hold the casing together. This part is considered a COTS. The screw will be approximately 1/8” x 1” and made from steel for durability and reduction of costs. McMaster-Carr sells what we will need for less than $10.00 for a pack of 100. McMaster-Carr is Team Eights primary supplier but this part will be shopped around to obtain a cheap contract for the manufacturing of the vacuum.

Overall, the assembly of the entire vacuum is a combination of a pancake and axial assembly process. Referring to the exploded and final assembly view (Figures 2 and 3), the motor, fan backing, fan, shroud, and filter are assembled in that order axially. Then both halves of the casing are screwed in around the axially motor assembly. End caps are snapped into place, nozzle secured, as well as the handle and battery pack.
Figure 9: Here is the exploded view of the final CAD assembly
Using Solidworks Costing Add-On feature we were able to obtain an approximate estimate for how much each component would cost if we were to produce 100,000 units. This software considers the manufacturing process and the material of the part and outputs a price. We then used Custom Part Net to calculate the labor cost associated with each part. Below is a table that shows what each part costs to manufacture including labor.

*Table 1: This is the BOP table that shows each item, the process used to make it, the material used to make it, the quantity produced, and the cost per unit with an overall cost of the entire assembly*

<table>
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<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>Process</th>
<th>MATERIAL</th>
<th>QTY.</th>
<th>Cost Per Unit in lot of 100,000</th>
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<td>casing</td>
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We previously created a specification declaring the cost of the vacuum would be below $60 to consumers. Our total cost to manufacture this product is about $63. That price does not include a profit markup. When considering a reasonable markup of $27 per vacuum, the vacuum will cost around $90 to purchase off the shelf.

Team Eight is aware the product is a bad investment for college aged consumers, as the price is too high. Although this is out of most college students’ budgets, this is still a reliable and effective product.
because it has great suction power, compactness, is ergonomically sound, and is made of high quality materials.

We appreciate working with ACME Tool Company, and we will continue informing you of our progress.

Thank you,

Team Eight

References


To: ACME Tool Company
From: Team Eight (Joe Roberto, Austin Schollenberger, Alan Zimmerman)
Subject: Final Prototype Memo
Date: December 11, 2015

Dear ACME Tool Company,

We are incredibly excited to present to you our final prototype. The point of this memo is to inform you how we constructed our final design and the results of its tested functionality. We will further explain the construction process, performance, and a review of our entire prototype. Overall our vacuum looked almost identical to our computer design model, but the suction was not enough due to a lack of structural support for the motor mounts.

We first began our construction phase by creating our 2.75” diameter centrifugal fan from 3D printing plastic material and used the Water Jet to cut two donut-hole pieces of polycarbide to act as the motor mount. We also used the Laser Cutter to cut a donut-hole shroud out of acrylic plastic (Figure 1). Using the Laser Jet, we made an acrylic piece to wedge onto the motor shaft to connect the shaft into the back of the fan.

![Figure 1: A. Fan, shroud, and motor mount.  B. Acrylic piece that fits onto the motor shaft and into the fan.](image)

We then made our filter out of window screen, acrylic, and glue. We angled two pieces of window frame on top of each other to create a small pore size and then sandwiched the frame between two donut-shapes pieces of acrylic for structural rigidity. We then glued this together along the rim of the donut (Figure 2).
Once the filter was made, we pursued printing our casing design. We originally had a 3D print design that split the case axially into two pieces, and it had built-in screw holes (Figure 3), but due to printer complications, we built our casing of 3” diameter PVC pipe (Figure 4).

*Figure 12: Homemade filter.*

*Figure 13: Computer model of the casing.*
After the PVC casing dried, we drilled vents into the fan (Figure 4) using a ½” drill bit thus allowing for exhaust and better suction. Then, we glued the filter inside of the PVC. We then rewired the motor to change the starting mechanism from a variable trigger to a switch. Using the Laser Cutter we cut a circular end cap of acrylic, where we cut a hole through to allow for the wiring to run through as well as a notch for the switch to protrude out of (Figure 5).

Figure 14: PVC casing. This picture was taken while zip ties were around both barrels of the casing to keep the glued interface (purple area in the middle) tightly together to allow for better glue bonding.

Figure 15: Motor system connected by wires to the switch and fed through the end cap.
A similar end cap was created for the pipe opening directly below the where the motor fits into. To empty the collection compartment, we laser cut two pieces of acrylic and glued them together to create an end cap that had an interference fit with the front pipe opening (Figure 6).

The next big step was to press fit the entire motor system (motor, motor mount, fan, end cap, and switch) into the back of the PVC pipe and spray painted it two coats of gray (Figure 7).
Once this dried, we glued our 3d printed nozzle onto the front of the vacuum, and we screwed our purchased metal handle onto the top of our vacuum to complete the construction of our prototype (Figure 8).

Below is our exploded view of our prototype with all of its components (Figure 9). Due to the nature of our vacuum assembly, we were unable to take a picture of a real exploded view, so we have created the best version of one as we could.
The change from a 3D printed casing to a PVC casing affected the performance of this prototype. The 3D casing included motor mounts, screws for easy separation, and a place for the filter. With the PVC we were forced to plunge the motor, fan, and filter all down into the tube. This limited our ability to test the performance of our vacuum, and eliminated the ability to easily change the filter. Before the motor was inserted into the PVC, the fan was hooked up and tested. There was optimal air flow when this test was conducted. After the vacuum was put together testing was minimal until our presentation due to scare of a catastrophic failure. When the vacuum was finally tested the performance was expected. The vacuum performed well for the first several seconds when it picked up 0.062 lbs of rice. The fan quickly became unbalanced causing it to collide with the casing resulting in limited suction. With the 3D printed
casing the motor mounts were built into the wall of the casing which would have ensured the fan and motor stayed square to the opening.

Our first prototype was all about feel. There were no working parts in this prototype. Despite this, our first and last prototype look very similar. Our first prototype featured three issues that were changed for our final prototype. The first change was the handle. The first prototype had a thick, awkward handle. Although it wasn’t our first choice, for the final prototype we narrowed the handle to make it sit in the hand more comfortably and set it further back on the drill to balance the vacuum better. The second adjustment we made was the nozzle. A simple angle was added to the end of the nozzle providing a better contact angle to allow the user to pick items up with less strain on the wrist. The last change we made was to use a bigger casing. The 2” casing on the first prototype was too small to allow us to fit a good fan and hold a fair amount of debris. Because of this we bumped the 2” diameter up to 3”.

Our second prototype was also very similar to our final prototype. The only changes were that we added a filter, better nozzle, and purchased a new handle.

The prototype still has room for improvements. For one the nozzle needed to have a larger angle on it. The current angle still requires you to elevate the vacuum quite high to lay it flat against a surface. In addition to that the cross sectional area of the nozzle opening needs to be significantly reduced again. This would help to improve the suction the vacuum can provide. The mount in between the fan and the motor shaft could also be improved. The fan became unbalanced too easily. A more sturdy backing that was thick enough to envelop the entire shaft would be best. There were also aspects that worked well in our prototype. The double barrel design worked like anticipated. The rice hit the filter and fell down into the collection barrel. This allowed us to have more room for storage. The filter also worked well. It allowed more than sufficient air flow while not allowing any debris to penetrate it.

Overall we were very pleased with our final product since all three members of our team are inexperienced with machining, had to come up with a new casing design within 4 days, and had to balance busy time schedules. Although there were many things that went wrong with our final prototype, we learned from our mistakes. We know that a more secure motor mount and fan backing are needed. We also know to reduce the nozzle area and possibly design a fan with a larger radius to provide more suction. We hope you recognize our hard effort and time we put into this project and that you will consider us designing more products for ACME. We thank you for working with us; it was a pleasure.

Sincerest Regards,

Team Eight