

Lab Toner Vacuum Cleaner Caddy

Mechanical Engineering 460: Senior Design

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The 3M logo is rendered in a bold, red, sans-serif font.The Lexmark text logo is in a large, black, sans-serif font, with a small "TM" trademark symbol at the top right of the word.

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Abstract

This report intends to outline the work performed in developing a design for a toner vacuum cleaner caddy for Lexmark. The main objective of this caddy renovation design is to increase the ease of use of the vacuum. To provide easier use, the design was developed based on concepts of body layout to improve attachment and equipment storage, as well as provide a more convenient way to start the motor.

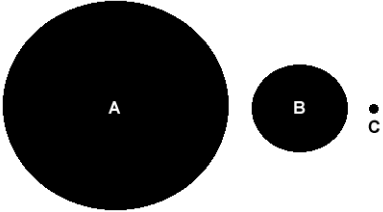
Introduction/ Objectives

Background

Lexmark International is a global technology company leading the industry in imaging and output solutions. The company headquarters is located in Lexington, Kentucky, where there are numerous production and research labs. Within these labs are printers and related equipment that may contain ink and toner products. The Electronics Vacuum 497 Series is used specifically for toner at Lexmark. While a regular industrial shop-vacuum can accommodate for most of the dirt and debris of the plant, the toner vacuum is critical for the thorough cleaning of labs and equipment at Lexmark.

Most dirt and debris is exponentially larger than toner. While regular vacuum filters can accommodate very small dust particles, a special tool is required to capture the particles that are smaller than the human eye can see. “One micron is equal to one-millionth of a meter, or 1/26,000 of an inch. On average, the human eye cannot see particles that are smaller than 50 to 60 microns” (Nilfisk). Table 1 presents a visual aid for the size comparison of micron values.

Table 1: Micron Size Comparisons

			(Reference: Nilfisk)
Label	Size	Description	
A	100 microns	Diameter of a human hair	
B	50 microns	Smallest particle visible to the human eye	
C	0.5 microns	Atmospheric dust	

The need for ridding equipment of the smallest particles of toner and dust is not just based on preferential cleaning habits. “Small particles in the air, on the floor, and on your machinery can be dangerous for a number of reasons. Most importantly, they can contaminate your product and endanger your workers' health... Particles that are 10 microns or less are considered respirable and can settle deep into the lungs – often causing adverse health effects” (Nilfisk). Although the risk of the smallest dust particles is common in any industrial setting, as a printer-based facility, the environment at Lexmark presents an obvious problem due to the miniscule particles of toner.

“Toner [is a] powder used specifically in laser printers and photocopiers to form the printed text and images on the paper. Toner particles are melted by the heat of the fuser, and bind to the paper.

Although traditionally the average size of toner particles was 14–16 micrometers diameter, the particle size of more current toner products has been reduced to 8–10 micrometers in order to obtain 600 dots per inch resolution. Particle size and particle size distribution are critical in order to produce a powder suitable for use in printers” (Malvern)

The Electronics Vacuum 497 Series has the ability to trap particles as small as 0.3 micrometers with its fine particle filter. As current toner is approximately 8-10 micrometers, the filter in the vacuum is highly effective. Due to the importance of cleaning up the toner in the Lexmark facilities, the vacuum has become a widely used tool throughout the plant.

Dave Merrifield, a principal mechanical engineer, specializes in printing at the Lexmark headquarters, in Lexington, Kentucky. He, along with hundreds of other users, has found that the current vacuum design does not reach certain ease-of-use standards. Figure 1 shows a brief description of the original vacuum, as well as a few of the vacuum's key features.

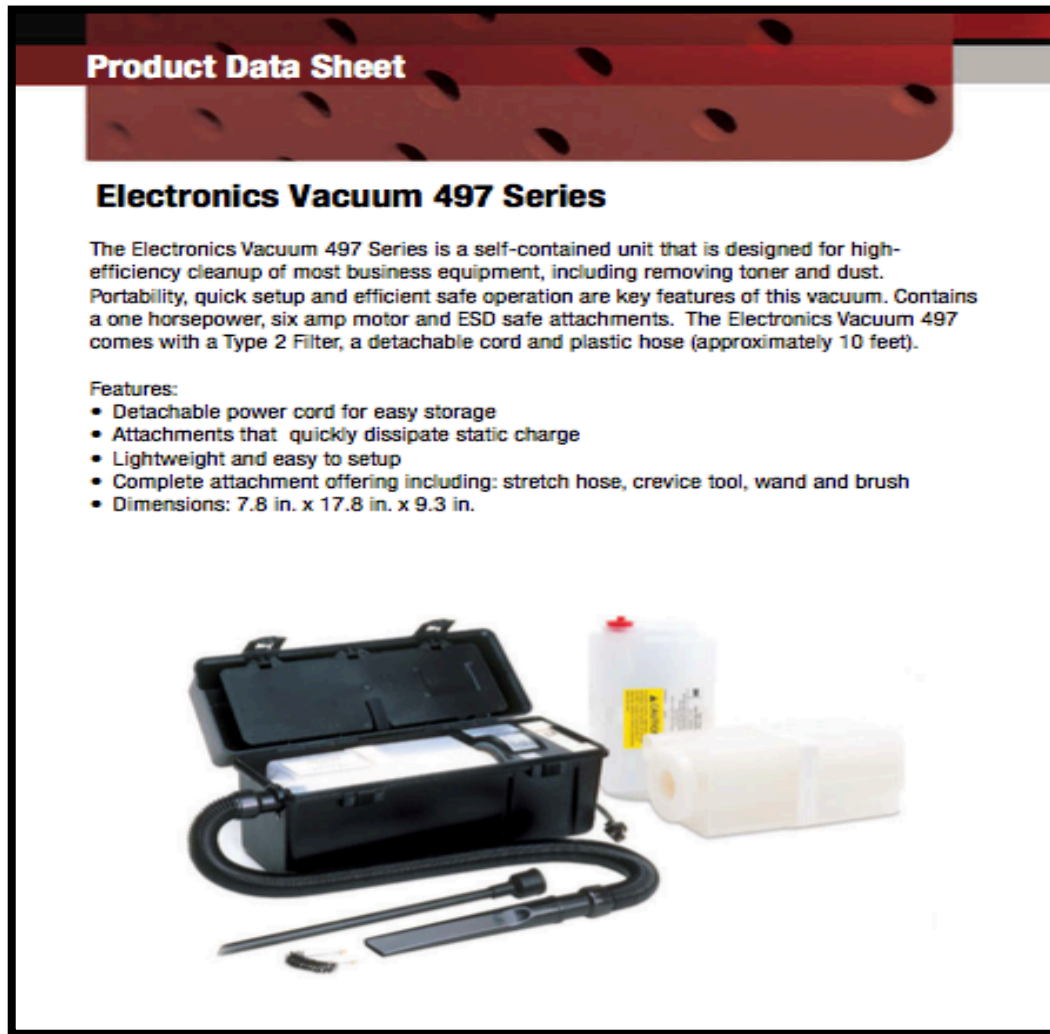


Figure 1: Product Data Sheet for Original Design

Figure 1 declares that the purpose of the Electronics Vacuum 497 Series is to remove small particles such as toner and dust from business based equipment with safe and efficient operating possibilities. The data sheet emphasizes the easy storage and setup capabilities of the vacuum in accordance with the attachments, hose, and power cord.

However, in presenting the project problem to our group, Dave Merrifield introduced several issues that users have discovered that contradict the convenience claims made by the data sheet. Figure 2 displays the operation instructions for the Electronics Vacuum 497 Series. According to the manual, there are nine main steps in operating the original vacuum. Table 2 in accordance with Figure 2, explains the issues with each of the steps in operating the vacuum.

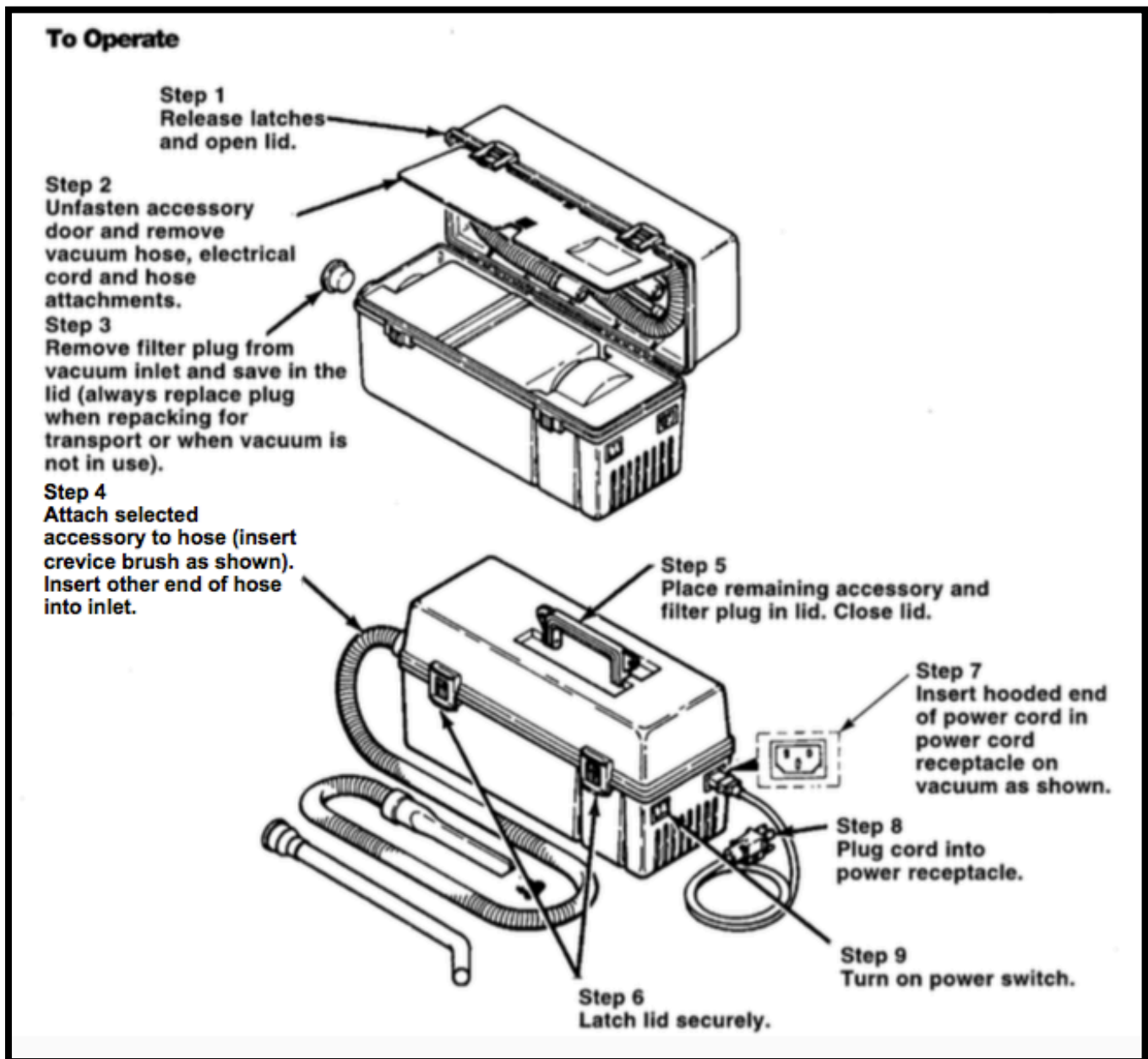


Figure 2: Operation Instructions for Original Design

Table 2: Operation Step Issues

Step Number	Current Operation	Issue
1	Release latches and open lid.	Opening the vacuum cavity and accessory door at the beginning of every use and each time an attachment is changed is inconvenient and requires tedious work.
2	Unfasten accessory door and remove vacuum hose, electrical cord, and hose attachments.	
3	Remove filter plug from vacuum inlet and save in the lid (always replace plug when repacking for transport or when vacuum is not in use).	According to Dave Merrifield, the vacuums used at Lexmark are rarely found with filter plugs. This plug was lost easily and not necessary for the success of the vacuum's primary functions at Lexmark.
4	Attach selected accessory to hose (insert crevice brush as shown). Insert other end of hose into inlet.	With the current design, hose attachment placement requires two hands, and therefore forces the user to pause the progress of the job. Also, during each vacuum use, the hose must be taken out of the vacuum cavity and connected. As a mobile vacuum, the transportation during operation should not require hose removal and replacement each time.
5	Place remaining accessory and filter plug in lid. Close lid. Inconvenient	Each time an attachment is switched, the vacuum must be turned off, the vacuum cavity and accessory door must be opened, the parts must be switched, the attachment must be placed on the hose with two hands, and the cavity must be shut before restarting the vacuum. The current storage of the attachments proves incredibly time consuming when using more than one attachment for a certain job.
6	Latch lid securely.	Because the lid must be opened and closed several times during each use, the latches are less reliable.
7	Insert hooded end of power cord in power cord receptacle on vacuum as shown.	Similar to the hose, for each vacuum use, the power cord must be removed from the lid cavity and plugged in to the motor. As a mobile vacuum, the transportation during operation should not require power cord removal and replacement each time.
8	Plug cord into power receptacle.	This step is unavoidable and will be included in future designs.
9	Turn on power switch.	The power switch is located in an inconvenient spot of the vacuum that makes it difficult to start and stop the vacuum efficiently.

Objectives:

The purpose of our project is to create a much more user-friendly vacuum for the Lexmark facilities. To accomplish this goal, our objectives are to improve storage, management, and transportation ease for this vacuum. The storage of attachments, hose, and power cord should be much more convenient and practical. Likewise, the operation of the vacuum should require less effort in unnecessary tasks. Finally, as stated in Table 2, as a mobile vacuum, the transportation during operation should be much simpler. The new design of this vacuum is intended to combine or eliminate several of the originally suggested operating steps, as well as provide more tactical approaches to managing the vacuum overall.

Phase I: Organization/ Planning

To begin tackling our project, we first consulted with all superiors on the requirements of the project, and created a document to outline the project expectations, which can be found in Appendix A. The project expectations are categorized by hardware and documentation. The hardware requirements explain the desired criteria for the final product of the vacuum. These include that all aspects of the vacuum must make it easy to use, carry, clean, and store. The documentation requirements explain the desired paperwork that will drive the design to success. These include all information to reproduce the design as well as the analysis and calculations that prove its superior design. Overall, the vacuum created should be a reproducible, user-friendly device that suppresses the complaints of the current vacuum.

Once the basic expectations were communicated clearly, we designated specific roles within our team, based on skillset and preference, to perform in throughout the project process. From there, we delegated tasks accordingly to the appropriate member of the team. These roles included a Gantt chart lead, a secretarial lead, a CAD model developing lead, and a resident retraction specialist. The team members holding each role are Spencer, McLean, Treavor, and Rob, respectively. While each team member assisted the others with the process, these roles were designed to keep the project management organized and equitable.

Once that was done, progress goals were set for the entire design process using the Gantt chart. The Gantt chart is our vacuum design organizer tool. We used Microsoft Project to generate and map out our dual semester schedule to keep the team on target for meeting our goals and deadlines. The chart breaks down the senior design project into several phases and sub-tasks to complete during the course of the entire design process. It includes phases such as brainstorming, concept development, testing, etc. The

chart begins on September 13 and ends on May 1st. The chart also incorporates major project milestones that mark when important tasks and accomplishments have been completed and achieved, such as the completed CAD design on January 20th and the Senior Design Fair on April 28th. Refer to the Appendix B for more detailed information and specific dates on individual items in the Gantt chart.

Finally, we organized weekly meetings as a group, with Dr. Steve Foster, and with Dave Merrifield to remain focused on our goals as a team throughout the process. Through collaboration with our superiors, we were able to outline a productive process to live by for the entire senior design project timeline.

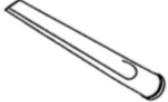
Phase II: Brain Storming

In order to create a new design for the vacuum, we first had to brainstorm ideas of all of the possibilities of how to improve the vacuum's ease of use. Eventually, we narrowed down the ease of the vacuum's use to four categories: attachment storage, body shape, power cord and hose storage, and power switch option. Because there were four categories and four team members, each team member was assigned one to research extensively and present to the rest of the group. This way, each category could be researched more thoroughly and information backed preferences could be developed for each category.

Attachment Storage:

Attachment storage can be further defined as the location, function, and convenience of the storage of the vacuum's several hose attachments. This vacuum comes with five hose attachments, which are shown and described in Table 3. To improve ease of use of the attachments, the new vacuum design must contain organized, convenient storage space to accommodate all of the five attachments.

Table 3: Hose Attachment Accessories

				
Dusting Brush Static Dissipative	Crevice Nozzle Static Dissipative	Crevice Brush	Needle Nose Nozzle Static Dissipative	Curved Wand Nozzle Static Dissipative
Used for applications involving static sensitive electronic components (such as circuit boards) to prevent static buildup.	Used for general cleaning of loose materials in accessible areas. Prevents static buildup.	Used with crevice nozzle for general cleaning where a brush is needed to loosen foreign material. NOT Static Dissipative.	Used primarily for cleaning circuit boards. Needle nose design permits cleaning in very small areas, and static dissipative properties prevent static buildup.	Used for general cleaning on hard to reach areas. Static dissipative properties prevent static buildup.

In the current design of the vacuum, a large cavity in the lid serves as the joint storage space for the five attachments, hose, power cord, filter cap, and user manual. This cavity makes for a very cluttered fit that lacks convenience. In a new design, we hoped to create a more organized layout for the

attachments, while allowing easy access during vacuum use. Six main designs were considered for attachment storage, and are shown in Table 4.

Table 4: Attachment Storage Options

Tackle Box Storage	Bag Storage	Shadow Box Storage
		
Rotary Wheel Storage	Cup Storage	Hook Storage
		

The concepts on the first row of Table 4 were the most favored after research. The first option is a tackle box type storage lid. This design, similar to a fishing tackle box, features a top accessed array of slots shaped to accommodate each attachment. This concept would be implemented into the vacuum's original design by repurposing the lid space and allows for organized, easily accessible attachment storage without redesigning the bottom half of the original vacuum. This design improves the ease of access during operation by allowing the user to reach the attachments without having to open the entire cavity of the vacuum. The problem with this concept is that it would not account for space for the desired form of power cord and hose storage. The second option is bag storage. Bag storage for attachment would allow for easily accessible attachments with variable pocket designs surrounding the base that could benefit the rest of the design due to its flexibility. A bag layout would be designed to connect to the current vacuum to accommodate all attachments, including the hose and power cord. However, no matter

the fabric, bag storage presents a difficulty in cleaning considering the device is dealing with toner. The third option is shadow box storage. Shadow box cavities allow for an organized, secure layout for the attachments, and could potentially evolve into a one-handed operation for attachment replacement. However, creation of this design would require exact dimensions of the attachments to be molded into a piece, and therefore, would become more expensive to create.

The concepts in the second row of Table 4 were found to be less practical for the use of this vacuum. The fourth option is rotary storage. Much like a Nerf gun, rotary storage was a concept designed to include all five attachments on a rotating wheel, for easy, quick switching. This concept however, was not favored because the different lengths and shapes of the attachments would require a very large rotary wheel. The fifth option is cup storage. Much like the original design, the attachments would be stored in a community bucket somewhere on the vacuum body. Cup storage would improve the current one by placing the bucket in a more conveniently accessed location, but ultimately this concept was not favored because the action on switching attachment would still require digging and making the switch with two hands. The sixth option is hook storage. To implement this design, the attachments would all be adjusted by adding a small hole to the base, and the body of the vacuum would contain several small hooks. The attachments would be stored by hanging on these hooks. This concept would allow for easy access to the attachments, but lacks a secure hold on them. Ultimately, the attachment storage concept fit best for this vacuum would be a combination of these ideas based on their positive and negative qualities.

Body Shape

While the shape of the body of the vacuum mostly depends on the other aspects of the vacuum, there are a few basic layout options that may help with transportation, accommodation, and overall management of the vacuum. The concepts studied on body shape are shown in Table 5.

Table 5: Body Shape Options

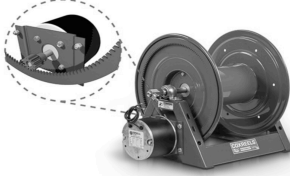
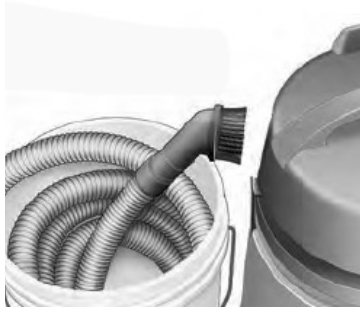
Top Handle	Backpack	Wheels	Additional Caddy
			

The first option shown in Table 5 is a concept similar to the current design. The means that the new case would be build as a unit, and the whole vacuum would be carried with a handle on top of that unit. This idea has been successful thus far with the current vacuum. However, in redesigning the vacuum to accommodate new storage features, weight limit must be minimized more strictly if the vacuum will be carried this way. The second concept in the table, a backpack design, must also accommodate weight. A backpack, however, distributes the weight more evenly on the user, and would allow for a higher minimum weight. The problem with a backpack design is that when dealing with toner, the vacuum gets messy. A backpack design would likely harm clothing and dirty the user much quicker. The third design considered was that of placing the entire vacuum on a set of wheels. While this would make it much easier to transport and store the vacuum, this would produce an annoyance while using the vacuum. Because the motion of vacuuming requires pulling the hose, a vacuum base on wheels would not be stable while operating. Finally, the last option researched for body design was a concept of creating an entirely separate case to place the current vacuum in. This case would allow space for all desired changes, but would ultimately be a waste of space and money without fixing the current designs most major issues. Overall, the most logical way to shape the body of this vacuum would be to imitate the current design.

Power Cord and Hose Storage

One of the most inconvenient tasks of managing the current vacuum is that of storing the power cord and the hose. The two combined, along with all of the attachments, barely fit in the storage bin that is the top half of the current vacuum. Due to this tight fit and inconvenient location, the user is often found leaving the power cord and hose attached to the outside, and the two end up just messily flopping around as the user tries to carry or store the vacuum. The best way to avoid this issue would be to create convenient, efficient ways to store the power cord and hose. The options we researched for doing so are listed in Table 6.

Table 6: Power Cord and Hose Storage Options

Spring Loaded Retraction	Power Cord Prongs	Motor Driven Retraction	Storage Well
			
Hose Retraction	Hose Prongs	Hose Pocket	
			

Power Cord Storage

The options shown in the first row of Table 6 are those pertaining to the storage of the power cord. The first option is a spring-loaded retraction system to manage the power cord. Spring-loaded retraction systems are typically driven by a constant force spring. These types of retraction systems are commonly seen in extension cords in a workshop setting. The spring is engaged when the cord is pulled off the reel. When the cord is pulled to the desired length, a catch mechanism stops the reel from rotating. When this catch mechanism is disengaged, the spring will wind the cord back on to the reel. The wires are connected to copper rings at the center of the reel. These copper rings can stay in contact with stationary prongs. The prongs are connected to wire terminals that connect with the rest of the electrical components.

The second option of hose retraction is a pair of prongs that could be placed on the vacuum body to store the power cord. Power cord prongs are typically seen on household vacuum cleaners. The cord is managed by two or more extrusions from the body. The cord is wrapped around these prongs until the length is managed, and will sometimes snap into place. Similar to a spring-loaded retraction, the power cord could also be managed by a motor driven retraction system. The cord reel can be controlled by an

electric motor. Instead of a spring and stop, a motor controls the extension and retraction of the cord. The last option considered is a well inside the vacuum. Similar to the current design, this type of storage requires only empty space in the body.

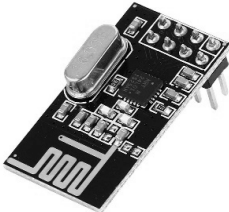
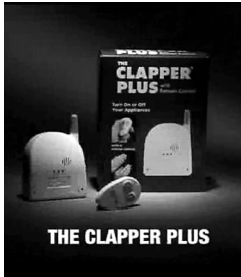
Hose Storage

The options shown on the second row of Table 6 are those pertaining to the storage of the hose. First, a hose retraction system was considered for the vacuum. The retraction system would be similar to a retractable compressed air hose. The hose would be wound on a spring-loaded reel that will pull the hose to the reel. The benefit of this system is that it would allow for easy storage. However, a retraction of a hose is much less logical than for a power cord because it presents more issues than advantages. A retraction system that could accommodate the hose for this vacuum would be hard to find and much to large. The second option researched for hose storage was a pair of prongs attached to the vacuum body. In contrast to the power cord option, hose prongs would route the hose around the entire body to manage the length and of the hose. The end of the hose would then be snapped into place to maintain a tight fit. The last hose storage option researched was that of an external pocket. Depending on the body of the vacuum, the hose may be stored in an external pocket or bucket. The hose would simply be placed into an open pocket for transport or storage.

Power Switching

The various options for switching researched include radio frequency (RF), accelerometer, sound control, and toggle switches. Two options for a toggle switch are relocating the switch to a more convenient place on the body and moving the switch to the handle. Table 7 shows pictorial representations of the various switching technologies.

Table 7: Power Switching Options

Radio Frequency Transceiver	Accelerometer	Sound Control	Toggle Switch
			

Radio frequency switching is a method that requires transmitting a signal over a specific wavelength and receiving the correct frequency to send an on signal to a transistor. For RF switching to work properly, both the transmitter and the receiver must be tuned to a frequency band that is narrow enough to limit interference but broad enough to negate the effects of communication errors. Both the transmitter and the receiver have a specific range which can be set which promotes some difficulties. If two systems are tuned to the same frequency and are looking for the same information, then if either transmitter is sending, both receivers will turn on.

To limit this effect, three options exist. Either the range must be small enough that the separate systems would have to be very close to each other, the frequencies of the two systems must be different, or the transmitters of the two systems must send different information on the frequency and each receiver must be tuned to receive this unique signal pattern. To limit the range of a transmitter or receiver the antenna must be short or the voltage from the power source is run at the bottom specification for the unit. To change the frequency of the systems would require different components on the board of the transmitter or receiver and would be difficult to accomplish with most commercially available units. The final option of sending unique information through the transmitter can be accomplished in two ways, an encoder or a microprocessor. Both processes would turn on and off the signal in a pattern and would look for the transmitter to receive the signal in the same pattern. The encoder would accomplish this by making various connections to the different leads to send out a different pattern of information and the receiver would route the information to a decoder which would pass a on signal to a transistor. The microprocessor would accomplish this by being programmed to send specific bursts to the transmitter and the receiver would have to route the information through an additional microprocessor which would be looking for the same information burst and would pass a high signal to a transistor. A transistor is required to be used as most of the receiver and transmitter systems run around five volts and the motor in the vacuum requires the standard 120 volts. Additionally, the motor draws six amps, which the typical transceiver cannot handle. The transistor will allow a small control voltage to turn on the power to the motor without harming the control circuit.

The accelerometer would require a physical input from the user to turn on the vacuum. This could be either attached to a pad on the vacuum or it could be placed in the handle of the vacuum cleaner. The signal would be sent to a latching relay which would turn on and off with each input from the accelerometer. The accelerometer would require a reasonable amount of force to be used to strike the location of the accelerometer, which could cause some issues over time.

Sound control could also be used to switch the vacuum on and off. This could be anywhere from the clapper to a custom system with a microphone and a microprocessor. For a custom system, the microprocessor would have to be programmed to analyze the input from the microphone for a specific intensity and frequency input. The programming would have to be distinct enough to isolate the control frequencies from the ambient noise and broad enough to be picked up by multiple users. This becomes particularly difficult when the vacuum is on and the system must be shut off as the vacuum creates a significant amount of noise.

The final option for switching is to use the current method, toggle switching. The toggle switch uses two contacts that are separate when in the off position and connected when in the on position. It is the most reliable option, as it is not affected by interference. The toggle switch could either be moved to a more convenient location on the vacuum such as the lid, or it could be routed up to the handle by a wire in the hose. Ultimately, all technologies would require a master toggle switch and should have a bypass switch whichever technology is chosen to improve system reliability should the chosen technology fail.

Phase III: Concept Selection

The next phase of our design process was to use the research we had done to select the concepts we would use in the design of our vacuum. To do so, each team member developed two full designs using preferential combinations of the design concepts researched. Each of the eight designs were unique, but was designed to accomplish similar goals. The eight design sketches are shown in Figure 3. While the sketches in Figure 3 show only the imagined shape of each design, Table 8 outlines the key features that each design included.

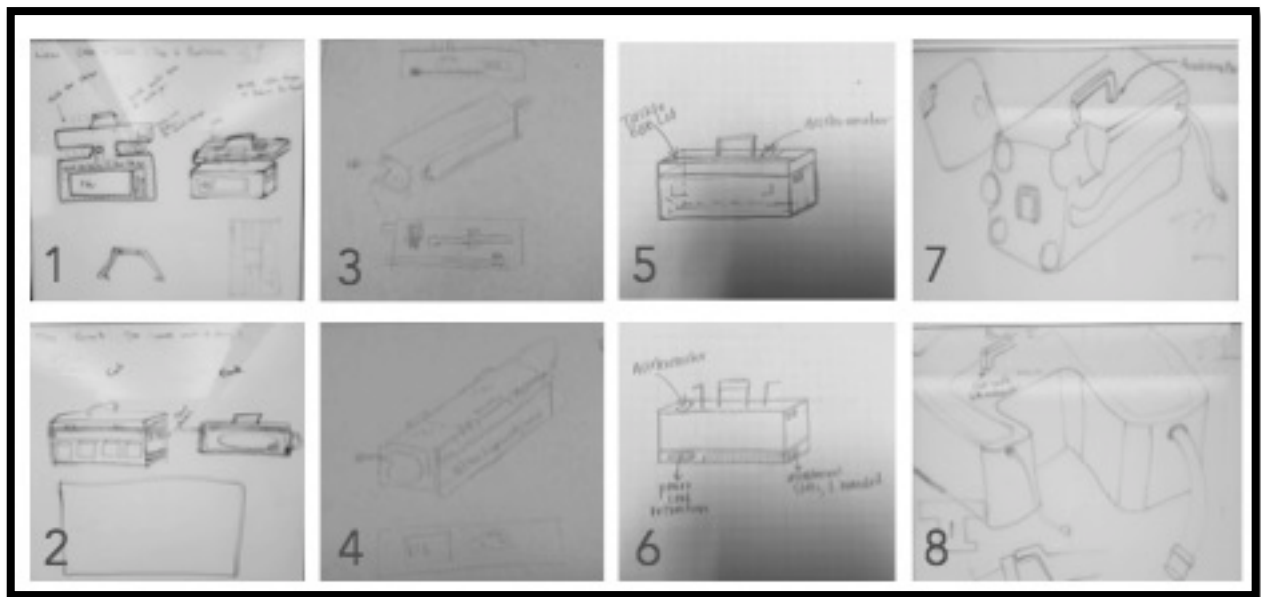


Figure 3: Concept Selection Part I

Table 8: Design Concept Features

	1	2	3	4
Attachments	Tackle Box	Bag Pockets	Snap In	Well
Body	Full Case	Added Bag Storage	Full Case	Full Case
Power Switch	Accelerometer & Bypass Switch	Same as Current	Accelerometer	Accelerometer
Power Cord	Spring Loaded Retraction	Bag Pocket	Spring Loaded Retraction	Spring Loaded Retraction
Hose	Prongs	Bag Pocket	Prongs	Well
Filter Access	Side Hinged Door	Same as Current	Top Hinged Door	Top Hinged Door

	5	6	7	8
Attachments	Tackle Box	Recessed Slots	Recessed Slots	Tackle Box
Body	Lid Replacement	Full Case	Full Case	Full Case
Power Switch	Accelerometer & Bypass Switch	Accelerometer & Bypass Switch	Accelerometer & Bypass Switch	Accelerometer & Bypass Switch
Power Cord	Spring Loaded Retraction	Spring Loaded Retraction	Spring Loaded Retraction	Spring Loaded Retraction
Hose	Prongs	Prongs	Recessed Slots	Spring Loaded Retraction
Filter Access	Top Hinged Door	Top Hinged Door	Top Hinged Door	Bottom Slider Door

Once the designs were created and presented to the group, we then put them through a Pugh diagram selection process. In this process, we critiqued each design based on our chosen selection criteria, which are as follows: durability, reliability, ease of use, ease to carry, security, cost, and aesthetics. Durability was defined as the designs capability of withstanding impact. Reliability was defined as the design's ability to perform effectively over time. Ease of use was considered as the combination of the processes of using, maintaining, and storing the vacuum. Ease to carry was used to judge the design's transportation ease based on the way it should be carried. We defined security as the vacuum's ability to accommodate all storage features effectively so that no parts would be lost or broken easily. Cost was a category that allowed for overly expensive production costs to be factored in to the design capability. Finally, aesthetics covered the design's overall appearance and maintenance. The aesthetics referred to the organization, cleanliness, and attractive visual possibilities of the vacuum. The scoring process of the Pugh diagram is shown in Figure 4.

Pugh Diagram									
Description	Datum	1	2	3	4	5	6	7	8
Photo									
Selection Criteria									
Durability		-1	0	-1	0	0	0	-1	1
Reliability		-1	-1	0	0	0	0	0	-1
Ease of Use		1	1	1	1	1	1	1	1
Ease to Carry		0	0	0	-1	0	0	0	-1
Security		0	0	-1	-1	-1	1	1	1
Cost		-1	0	0	0	0	-1	-1	-1
Aesthetics		1	-1	1	0	0	1	1	1
Total		-1	-1	0	-1	0	2	1	1

Figure 4: Pugh Diagram Part I

Design number 6 received the highest score through this process. This design was scored well based on its ease of use, security, and aesthetics. This design was deemed easy to use due to its recessed attachment slots that allow for one-handed attachment replacement, its spring loaded retraction technology for the power cord, its organized and convenient hose storage, and its overall general organized appearance. Likewise, this design was discussed to be no less reliable, durable, or easy to carry than the current design. Several other designs received similar positive feedback for various reasons, but had at least one other conflicting aspect that did not produce positive feedback when compared to the current vacuum datum.

Once this scoring was determined, our team decided that the winning design did not accomplish as many positive aspects as it should have to be considered a true improvement to the original vacuum. Because of this, we compiled the positive traits from several of the eight designs to create an entirely new design. This design can be found in Figure 5.

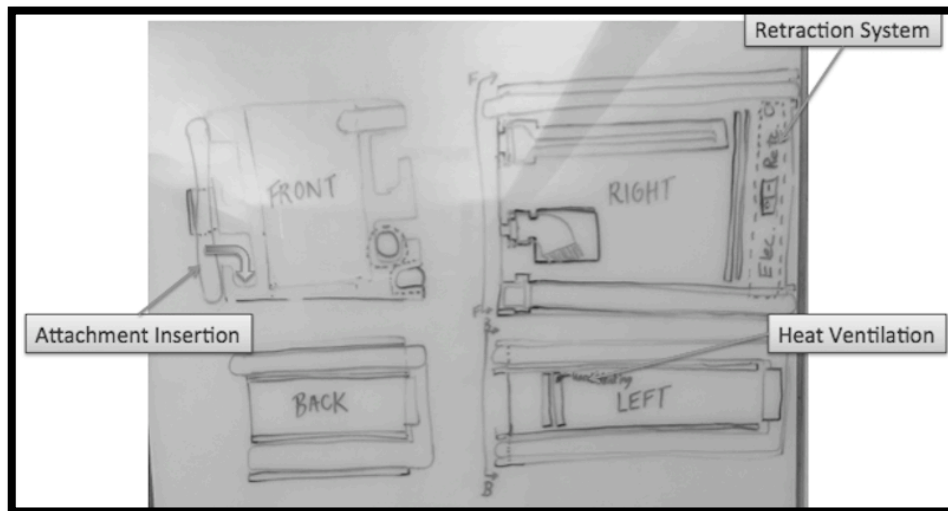


Figure 5: Concept Selection Part II

The updated design features concepts that received positive feedback from the first concept selection process. These include recessed attachment storage, one-handed attachment management, prong hose storage, a spring-loaded retraction system for the power cord, and an organized, easy to clean and carry body style. One option that this design allowed for manipulation was the access to the motor and filter cavity of the vacuum for installation and maintenance purposes. To make sure that the best option was chosen, we performed a second Pugh diagram selection process for the filter and motor access point. The Pugh diagram is shown in Figure 6.

Pugh Diagram				
Description	D1 - Datum	D2	D3	D4
Photo				
	Top w/ Hinges	Front Slider w/ Tray	Bottom Slider	Bottom Bolted
Selection Criteria				
Durability		0	-1	0
Reliability		1	0	1
Ease of Use		0	0	-1
Ease to Carry		0	0	0
Security		0	0	0
Cost		0	0	0
Aesthetics		1	1	1
Total		2	0	1

Figure 6: Pugh Diagram Part II

The four concepts compared in the second Pugh diagram concept selection process were a top hinged door, a front sliding door, a bottom sliding door, and a bottom bolted door. Because the top hinged door is most similar to the current design, that one was used as the datum for this Pugh diagram. Each of these options was very similar to the rest, and no extreme positive or negative traits were assigned to any. However, the front slider door did rank the highest through this process based on its reliability, aesthetics, and lack of negative features. The bottom doors presented durability and reliability risks as they would require for the motor and filter to be bolted to the top of the vacuum, rather than rest on the base. Ultimately, the second concept selection allowed us to choose the best access location for the filter and the motor to combine with the rest of the best solution ideas we gained from the first Pugh diagram process.

Phase IV: Final Design Development

Finally, after the brainstorming concepts were turned into rough designs, and the rough designs were broken down into desired concepts, the desired concepts could be recombined into a desirable vacuum design. After making a few adjustments to the design created from the second Pugh diagram concept selection process, the most current design could start being developed thoroughly.

Figure 7 shows an isometric of the current vacuum design. The body is made of eight plates with three on the right side and one taking up the other sides of the rectangular prism. The designed was split into plates to allow for easy manufacturing where the main shapes in the plates can be cut out on a water jet table or a plasma table. Additionally, the modular design allows for a quick correction or change without having to change multiple things as compared to other manufacturing approaches. All of the attachment storage has moved to a single side to limit the amount of plates that are used. The hose is only routed along the left side and the back and can be more clearly seen in Figure 8. The hose is guided by trays around the body and the end is locked into place using a magnet that is place on the body. The end of the hose will have a handle on it that will contain the RF transceiver and a metal band to attract to the magnet. Heat venting is included on both sides to evacuate the air from the motor and allow the motor to breathe.

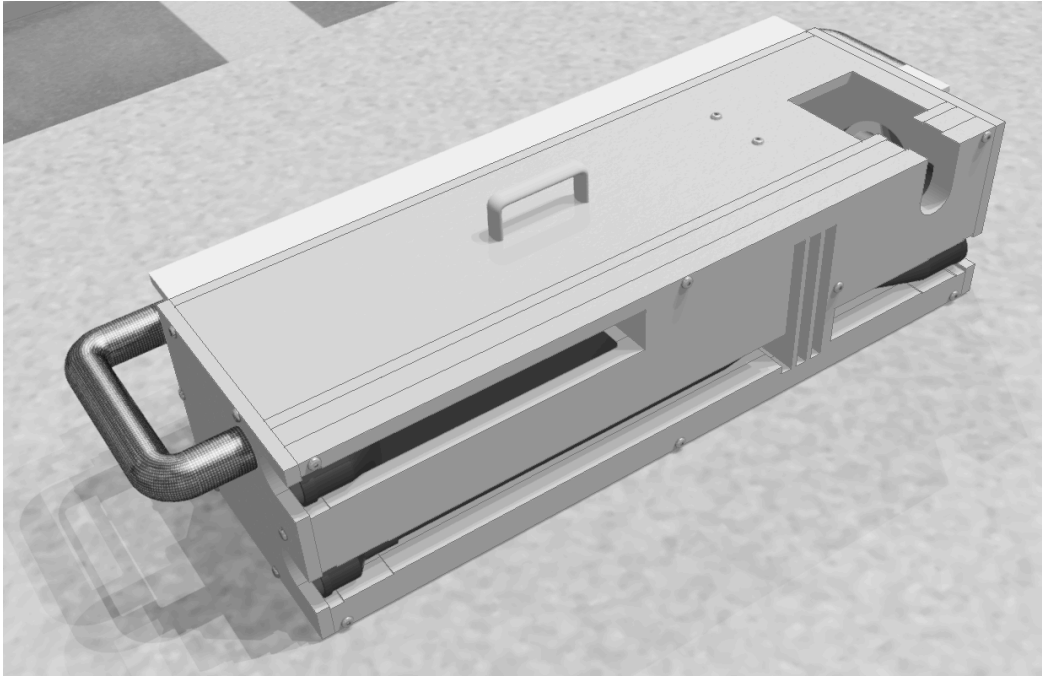


Figure 7: Isometric of Vacuum

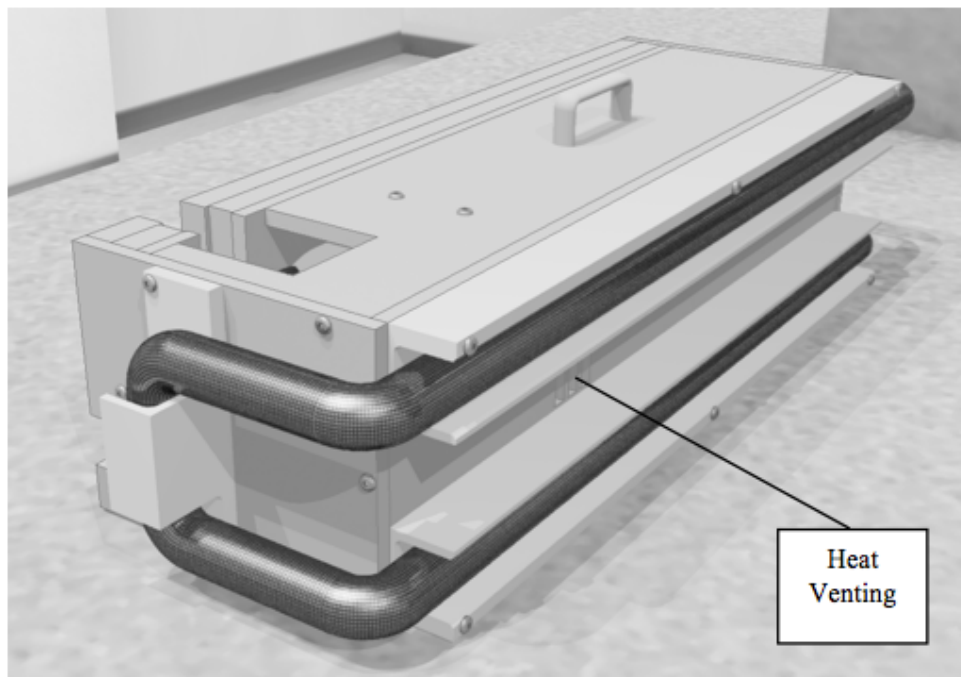


Figure 8: Isometric of Vacuum with Hose Routing

Figure 9 shows a top view of the vacuum with the top plate removed. It can be seen that there is room behind the motor with a plate separating that cavity from the cavity that houses the cord retractor. The space and the plate are to ensure that the motor has enough room to breathe while ensuring that the heat will not exhaust towards the cord retractor or the electronics which will be housed in the empty space around the cord retractor.

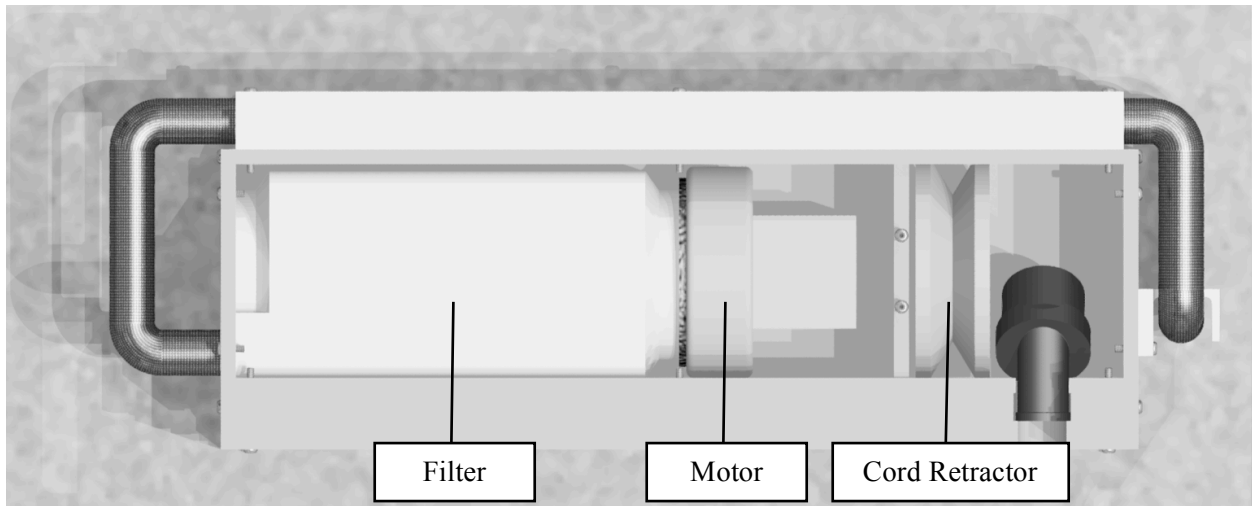


Figure 9: Top View of Vacuum Caddy without Top Plate

Figure 10, Figure 11, and Figure 12 outline the details for removing an attachment. First, the hose must be inserted into the attachment. The attachment will move forward off a magnet holding it in place and run into a wall, which will allow the user to force the hose into the attachment. The attachment can then be removed from the body. In order to store an attachment, the attachment must first be placed into the correct pocket. The Attachment can then be pulled towards the outer wall and it will run into the wall, which allows the user to remove the hose. Each attachment will have a metal band around it that will make contact with a magnet, which will hold it in place while not in use.

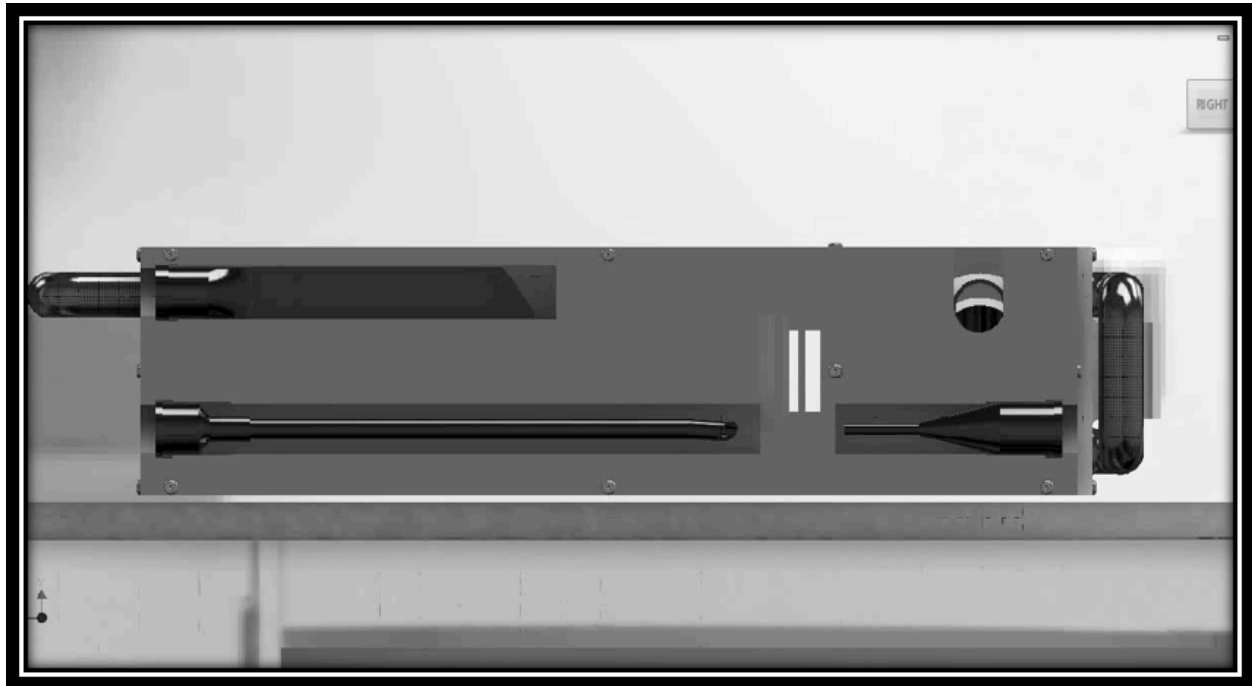


Figure 10 Right Side View



Figure 11 Close-up of Attachment Storage Cavity

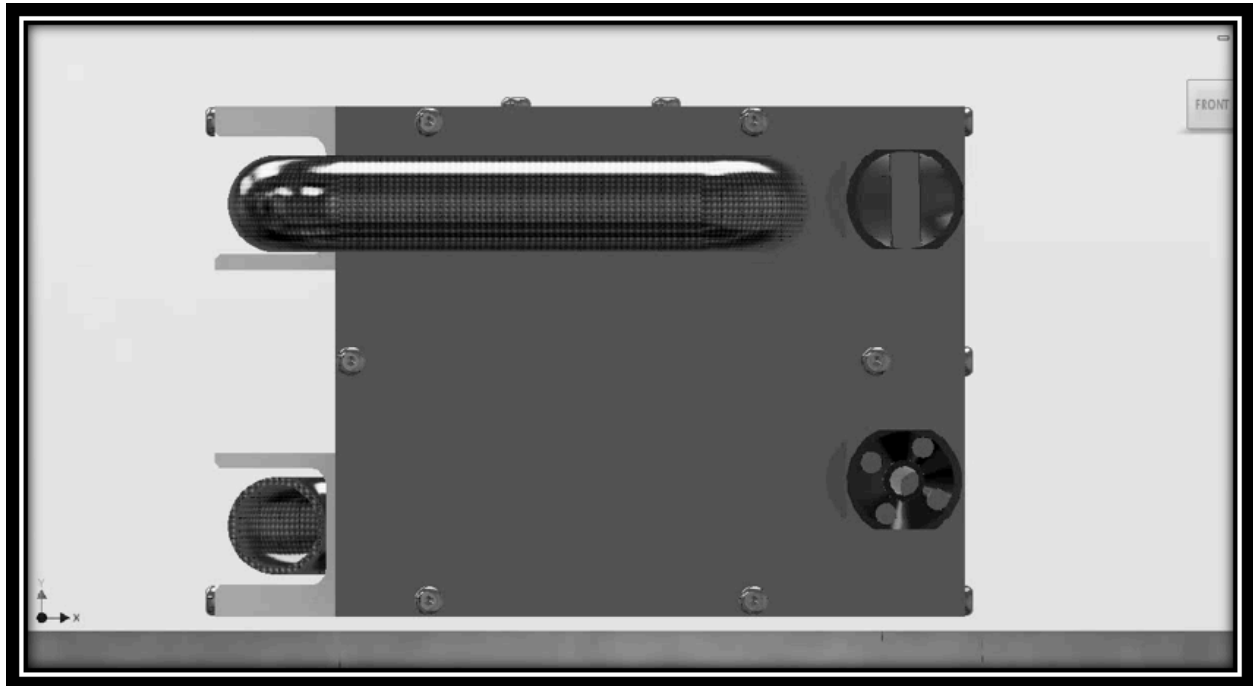


Figure 12: Front View with Attachment Removal Details

Phase V: Design Review

The first phase of the second semester was what we deemed our “Design Review” stage. While this description is rather vague, this phase was ultimately that. This process took up the majority of the semester, due to the required attention to detail. Through a series of design adjustments, drawing creations and corrections, and professor and sponsor approval meetings, the ultimate prototype design was created.

The prototype produced this semester consists of two major design features: the power cord retractor and the body of the vacuum. These two features were the most prominent because these were both fabricated from parts made through the Lexmark facilities. These two key aspects of the prototype required full parts drawings from our team to be used to manufacture the parts through the Lexmark facilities. These parts drawings were the basis of creation of the whole prototype, and therefore required much detail in specifications, tolerances, and design characteristics. A full list of the drawings for both the prototype power cord retractor and the prototype body can be found in Appendix C.

A description of each of the two major prototype design features can be found in more depth within this section. The key design choices of each feature will be highlighted and explained in more depth. Finally, discussion of the design review process with our professor and corporate sponsor along the way will be incorporated into this section.

Prototype Power Cord Retractor

To begin the production of the power cord retractor, an example power cord retractor was observed. Figure 13 shows the Kenmore power cord retractor that was used as an exemplary model for the design of our prototype’s power cord retractor.

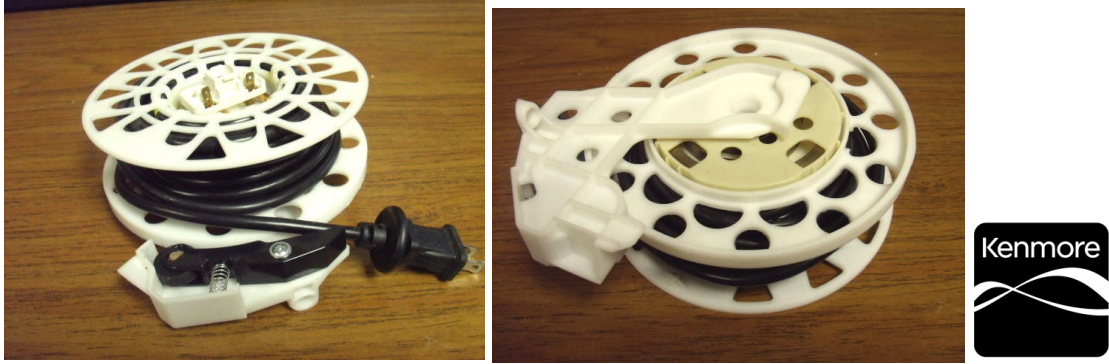


Figure 13: Kenmore Replacement Power Cord Retractor

Using ideas of shapes, connection details, and overall design features from the Kenmore replacement power cord retractor, the new retractor design could be created. The prototype power cord retractor was built from a series of seven Lexmark fabricated parts. These parts, as indicated by part number, are shown in Table 9.

Table 9: Prototype Power Cord Retractor Parts List

Part Number	Description
1.0.01	Spool
1.0.02	Arm
1.0.03	Slip Ring Mount
1.0.04	Shaft
1.0.05	Lever
1.0.06	Wheel
1.0.07	Spring Holder

While the part numbers are uninformative in the body of this report, the drawings are organized through this system in Appendix C. Likewise, Appendix C is where a more descriptive display of fabrication details can be found concerning each part. Table 9 does, however, list the names of the fabricated power cord retractor components, as labeled in Figure 14.

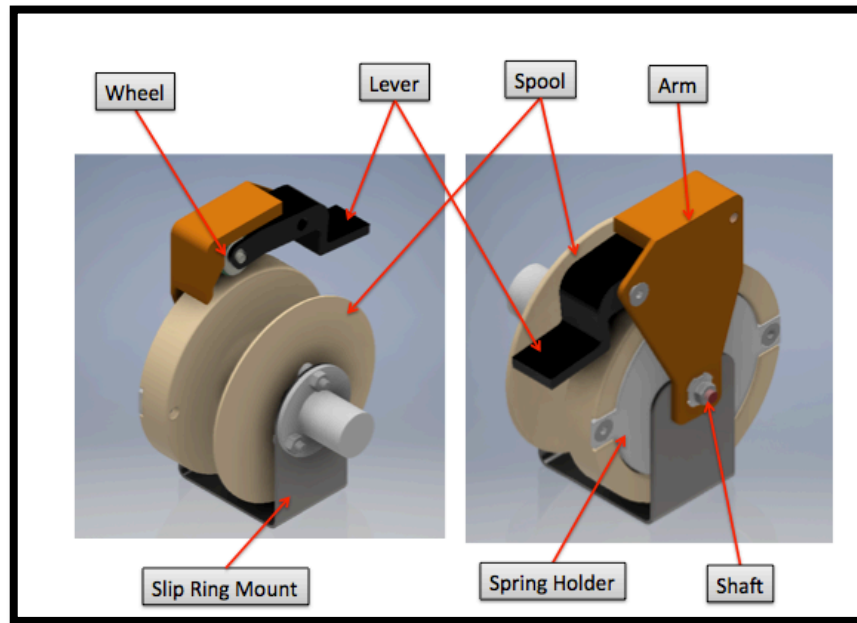


Figure 14: Power Cord Retractor Labeled

Figure 14 shows the power cord retractor, as 3D modeled, for creation through the Lexmark facilities. As Figure 14 shows, there is a spool in the center of the retractor, which serves as a storage location for the power cord. On the backside of the spool lays a spring, which is used to provide force for retraction of the power cord. The lever, arm, and wheel serve as a friction mechanism that controls the rotation of the spool. Figure 15 and Figure 16 show more detailed schematics of how the retractor was designed to work.

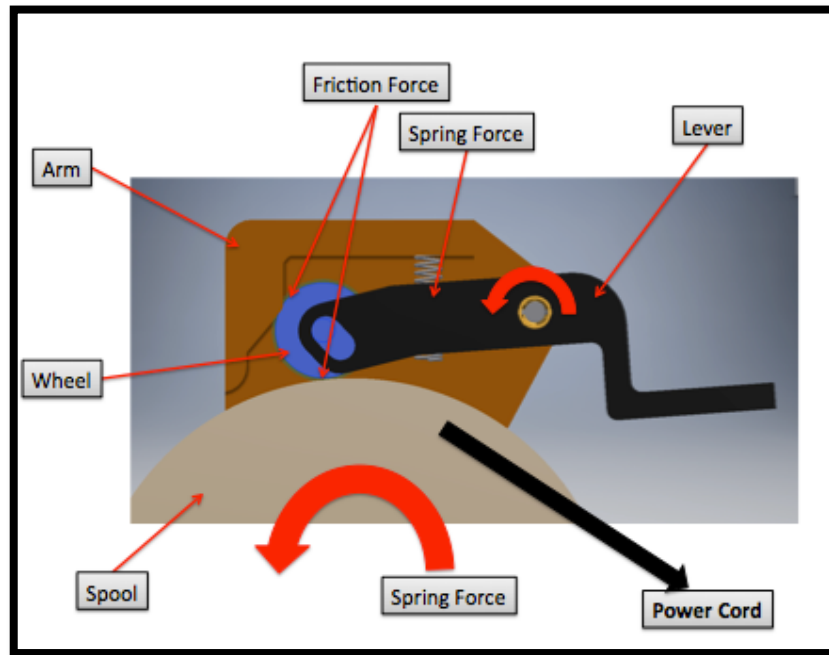


Figure 15: Prototype Power Cord Retractor Lever - Closed Position

Figure 15 shows the power cord retractor in the closed position. This is how the retractor would look when the vacuum operator is pulling the power cord out to plug in to the wall. The power cord may be still, but the arrow labeled “power cord” is the direction that the power cord would be pulled in this configuration. The spring force on the spool is contributing to the counter-clockwise rotation of the spool. However, due to the combined friction force of the wheel against the top of the spool and the arm, as well as the counter-clockwise spring force to the lever, the spool will not rotate counter-clockwise. The friction between the arm and the wheel combined with the spring force on the top of the lever does not allow the wheel to rotate clockwise in this position. Therefore, the resulting friction of the wheel and the spool does not allow the spool to rotate counter-clockwise. The wheel can, however, rotate counter-clockwise due to its configuration with the slot in the lever. This means that the power cord can be pulled out, but will not be pulled back in if the operator lets go of it. When the operator chooses to retract the spring, he or she would simply push down on the lever. Figure 16 shows the change of action based on this push force.

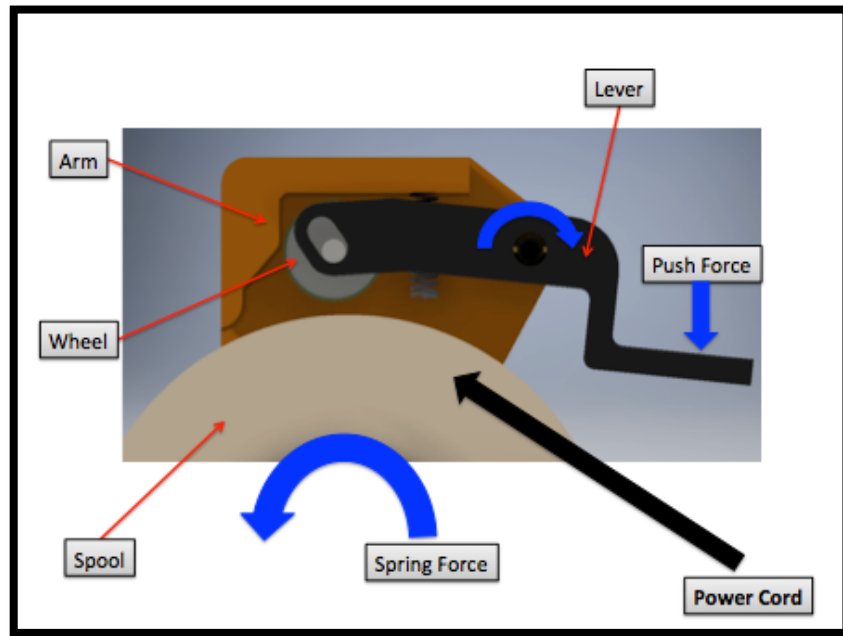


Figure 16: Prototype Power Cord Retractor Lever - Open Position

In contrast to Figure 15, this configuration shows the lever being pushed down by the user to allow for power cord retraction. In this configuration, the force of the push is stronger than the force of the spring on the lever, causing the lever to now have a clockwise force. With this push, the wheel is lifted from the spool, and the friction that existed between the wheel and the spool disappears. At this point, there is no force acting on the spool except for the spring force, which means that the spool will quickly rotate counter clockwise, winding up the cord. The arrow labeled “power cord” shows the direction that the hose will travel with the added push force in this configuration.

The retractor was designed for connection to the motor and wall within the internal compartment of the body of the vacuum, such that the power cord and retractor switch are both accessible from outside the cavity, but the retractor spool is contained within the body for appropriate storage. A further discussion of this connection will be addressed later in this report.

Prototype Body

The body of this prototype was ultimately built with a series of solid plates. In order to manufacture parts efficiently, these plates were designed strategically to mimic the desired shape of the final product. The plates of the prototype were identified by location on the body. A list of each of the plates as labeled by part number can be found in Table 10.

Table 10: Prototype Body Parts

Part Number	Description
2.1.01	Attachment Plate 1
2.1.02	Attachment Plate 2
2.1.03	Back Plate
2.1.04	Bottom Plate
2.1.05	Brush Tube
2.1.06	Front Plate
2.1.07	Hose Tray 1
2.1.08	Hose Tray 2
2.1.09	Hose Tray 3
2.1.10	Inside Plate
2.1.11	Left Plate
2.1.12	Motor Lock
2.1.13	Right Plate
2.1.14	Top Plate

While the part numbers are uninformative in the body of this report, the drawings are organized through this system in Appendix C. Likewise, Appendix C is where a more descriptive display of fabrication details can be found concerning each part. Table 10 does, however, list the names of the fabricated body part components, as labeled in Figure 17.

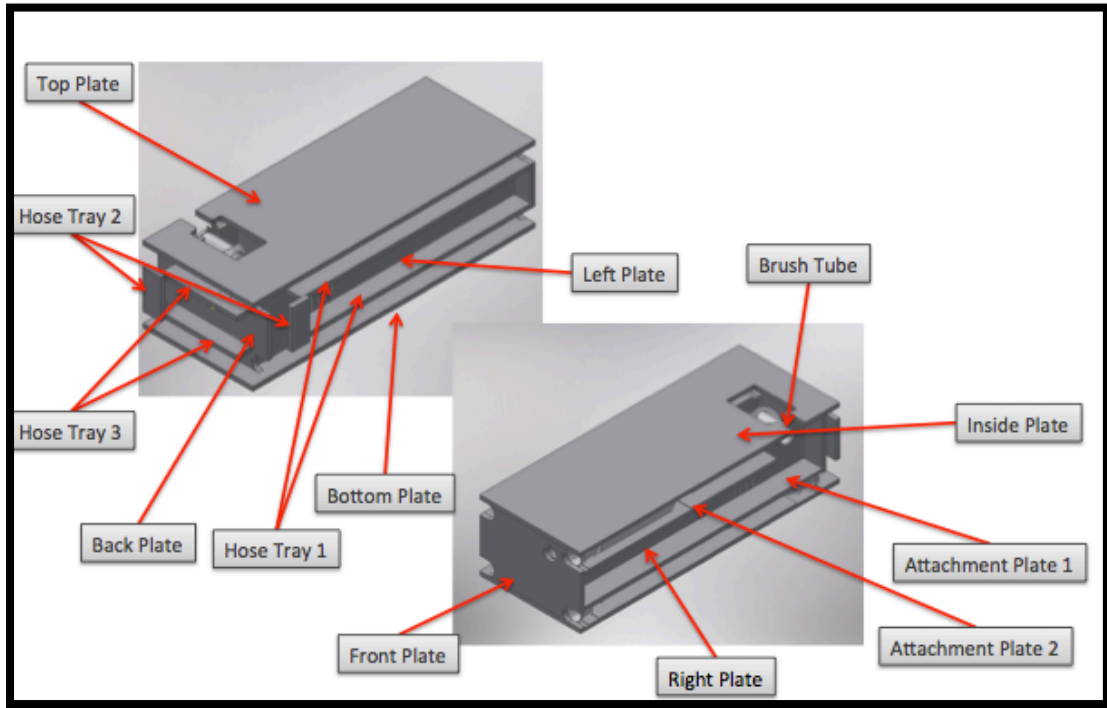


Figure 17: Prototype Body Labeled

Figure 17 shows the prototype body, as 3D modeled, for creation through the Lexmark facilities. Figure 17 also shows the locations of each plate with relation to the rest of the body. As shown, the plates are positioned such that there is a basic box shape, with a cavity inside and specific outside storage locations for both the attachments and hose. The hose may be stored along pathways built into the side of the vacuum, and attachments may be strategically stored according to shape and size.

Phase VI: Order Parts

To continue building our design, each of the parts needed to create the entire vacuum had to be acquired. These parts were categorized into three major territories: Lexmark manufactured parts, assembly parts, and power switching parts.

To have the parts ordered from Lexmark, the team sent the entire series of parts drawings in to Dave Merrifield for communication with the Lexmark facilities machinists. Having reviewed each part within design reviews and discussions throughout the first phase of this semester, this communication was rather simple. However, with the lack of time and the transition between having parts made, shipped and delivered, this process proved to take much longer than expected. Also, this process proved to be much more costly than we expected. From the cost of the materials of the parts, to the cost of the machinist's time to fabricate, our prototype ended up being a very expensive piece of equipment.

The assembly parts mentioned are those that allowed us to connect the rest of the manufactured parts from Lexmark. These include but are not limited to: screws, threaded inserts, dowel pins, washers, nuts and bolts, of various sizes. The shapes and sizes of each were specified based on location and connection requirements throughout the plates of the body.

Finally, the parts required to build the power switching mechanism for the vacuum were all separately ordered. The design of the switching mechanism for the prototype consisted of all electrical equipment necessary to construct electronic circuits for a remote control power switch with a backup toggle on/off switch. We ordered all of these parts separately from Amazon. Due to shipping conflicts, we struggled being able to find the correct parts within a timely manor. This was part of the reason we were unable to completely create the desired switching mechanism for this prototype.

Phase VII: Failure Analysis

After receiving parts to put together our vacuum, we reached the most frustrating, yet exciting, phase of our project process: failure analysis. For this section, the failures approached during this phase were categorized into three main sections: prototype body, prototype power cord retractor, and the power switch.

Prototype Body

The failures found while putting together the prototype body together were all related to incorrect or mismatched dimensions for the cuts into the body plates. Table 11 shows a full list of the prototype body issues, along with root cause analyses and solutions.

Table 11: Prototype Body Failure Analysis

Problem	Root Cause	Short Term Solution	Long Term Solution
Hose Path – did not fit hose	Measured the wrong diameter of the hose when designing	• Calculated space needed and milled out top & bottom plates accordingly • Updated drawing to correct measurements	Final design hose path will accommodate correct hose diameter according to diameter and interference required
Left Plate/Front Plate Connection Bolt Holes – were not there	Unclear documentation for the machinist	• Drilled appropriate holes to accommodate bolts • Clarified drawing specifications	Final design will not require these holes for connection as the pieces will not be separate
Motor Lock/ Side Plates Connection Bolt Holes – did not line up	Mismatched dimensions between drawings of motor lock and plates	• Slotted plate holes to match motor lock hole locations • Updated drawing dimensions	Final design will not require these holes for connection as the pieces will not be separate
Motor Lock/ Motor Connection – did not fit ideally	Incorrect measurements of motor diameter	• Shifted motor lock to fit on smaller portion of motor	Final design will not require this part as the pieces will not be separate
Bottom Plate is curved	When inserting threaded inserts, we deformed the piece	• Add bolts to the middle of the bottom plate to strengthen security	Final design will not have this issue considering the bottom piece does not stand alone

The first major problem involved the path that the hose was supposed to be stored along. Upon attaching plates, we realized that the spacing for this path was not wide enough to accommodate the hose. Through further observation, we realized that the top portion of the hose could fit into the slot, but the main accordion section of the hose could not. For this reason we realized that the root cause of this problem was a mistranslation between diameter measurements while creating the prototype model. To fix this problem for the prototype, we calculated the amount of space needed to accommodate the actual hose diameter, and milled the plates accordingly. The models of the plates were also updated to include this correction. Figure 18 shows the hose path having been adjusted to accommodate the correct hose length. For the final design, the path will be modeled for the appropriate diameter of the hose.

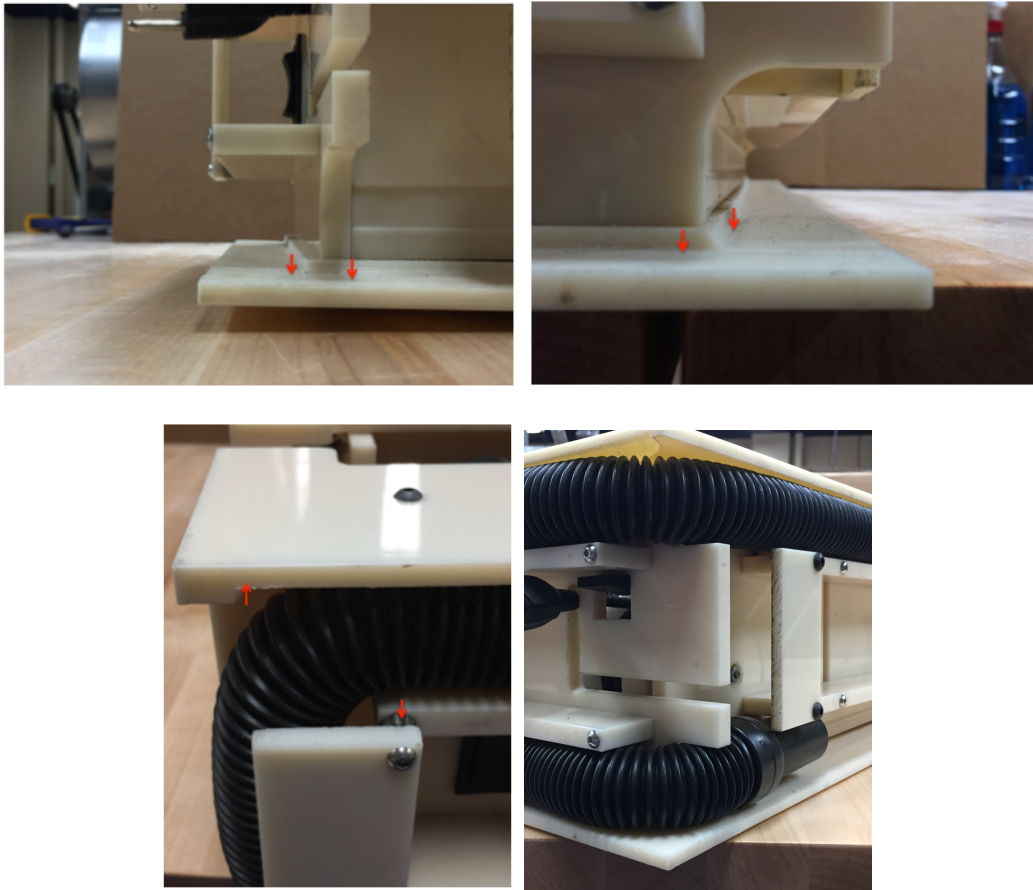


Figure 18: Hose Path Failure

The second major problem involved some missing bolt holes for threaded inserts. After examining our drawings closely, we noticed that the specifications were unclear that there should be holes

at that location. For this reason, the machinist easily missed this guidance, and did not insert the holes at all. Our short-term solution was to drill the appropriate holes to accommodate the required screws. However, for the final design, this will not be an issue, as this portion of the body will be one piece and will not require bolts at all. Figure 19 shows the location of this issue with the short-term solution put in to place.

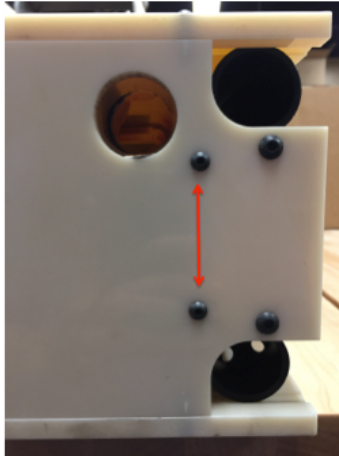


Figure 19: Bolt Holes Failure

Similar to the second problem, the third problem dealt with location of holes for the bolts. However, this one occurred in the connection between the motor cover and the left and right plates. The holes in the motor cover were spread too far apart for the screws to go through the matching left and right plate connection holes. By observing our parts drawings more closely, this was caused by a lack of attention and mismatched measurement between the two parts. Our short-term solution was to slot the holes of the plate to accommodate for the wider distance between the two motor lock holes. Similar to the last one, this issue will not exist in the final design because this connection will also be one piece and will not require bolts at all. Figure 20 shows the location of the holes, as well as the updated slot made for the short-term solution.

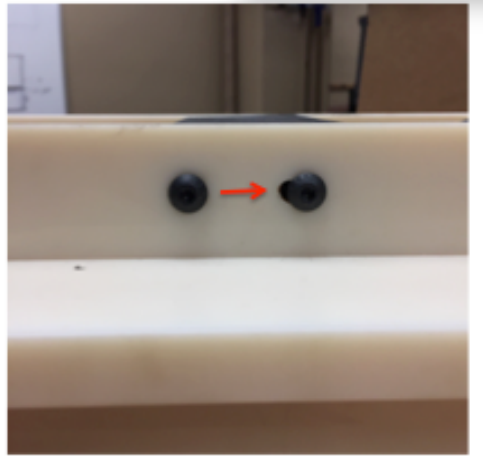


Figure 20: Motor Lock Bolt Failure

The motor lock also provided another failure for the building of the body. The cover did not fit on the motor appropriately, and therefore would not stay contained within the cavity of the body. After further analysis, we discovered that this mistake was made due to an incorrect measurement of the motor diameter. The measured diameter was too small, meaning that the motor cover could not fit around the actual motor. For a short-term solution, we removed one edge of the motor lock, and slid it one direction such that the diameter could circle the smaller portion of the motor. The final design will accommodate a motor cover that will appropriately fit the actual diameter of the motor. Figure 21 shows the motor lock updated for the short-term solution within the cavity.

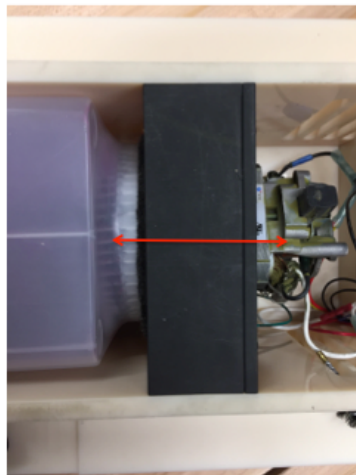


Figure 21: Motor Lock Failure

The final issue we discovered with the body of the prototype is the deformation of the bottom plate. Currently, the bottom plate curves such that the bottom of the vacuum does not lay flat on the table. After further analysis, we discovered that this might have been caused through a plastic deformation of the bottom plate during our milling processes. This also may be caused because the motor fits very snug inside the cavity, and may be putting extra pressure on the bottom plate. Right now, this issue is not causing and problems with the operation of the vacuum. However, if we added two bolts to the middle of the bottom plate, this would straighten out the base. The final design will not have this problem, as it will be a completely different attachment strategy for the bottom plate to the rest of the body. Figure 22 shows the curve of the bottom plate.



Figure 22: Bottom Plate Failure

Prototype Power Cord Retractor

The failures found while putting together the prototype power cord retractor together were each separate issues that withheld the retractor from operating correctly. Table 12 shows a full list of the prototype power cord retractor issues, along with root cause analyses and solutions.

Table 12: Prototype Power Cord Retractor Failure Analysis

Problem	Root Cause	Short Term Solution	Long Term Solution
Spring binding – spring did not function correctly	Too much axial pressure on spring	Added washers to extend length of larger diameter of shaft	Final design will include shaft with an extended larger diameter
Shaft/Left Plate Connection - Threaded shaft did not reach outside of body	Miscalculated the required length of the threaded shaft to reach through left plate	Milled out section of left plate to reduce wall thickness	Final design will include a shaft with a longer length of threaded portion
Power cord – torturous path for cord to flow through	Hole was located too far below track leading to friction points between corners of the access hole	- Measured required distance to eliminate friction points - Extended length of slot to allow cord to flow freely	Final design will include a more appropriately placed slot for cord access
Cord - would not wrap around spool easily	Cord diameter was too thick, not flexible enough	- Researched current vacuum retractable cords - Connected a thinner, more flexible cord	Final design will include the appropriate cord

The first failure addressed in accordance to the power cord retractor was that the spring was binding and did not function correctly. After many trials and adjustments, we discovered that the axial pressure was too high on the spring, causing the spring to bind. To fix this issue, we added some washers to extend the length of the shaft with the larger diameter. However, long term, the shaft would be remanufactured with that portion of the shaft having a longer length. Figure 23 shows the shaft being referred to in relation to the spring, as well as points out the extension of the larger diameter portion of the shaft.

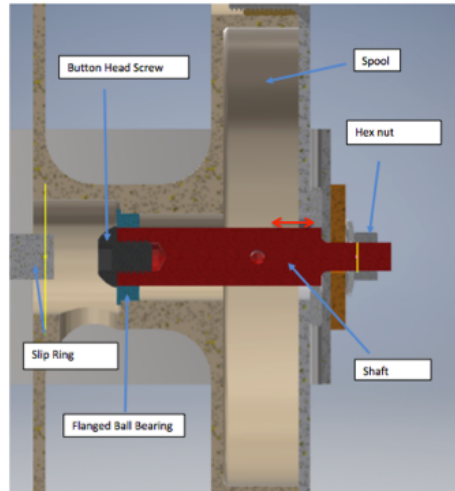


Figure 23: Shaft Failure

The shaft also presented another failure in its connection to the left plate of the body. The shaft was not long enough to reach out through the other side of the plate. This was caused by a lack of proper measurements when designing the shaft. For the prototype, we measured how much space was needed to accommodate the short shaft, and thinned out a portion of the wall so that the shaft could extend all the way through. For the final design, however, the threaded portion of the shaft will extend through to the other side of the left plate. Figure 24 shows the adjusted plate to accommodate for the shorter shaft.

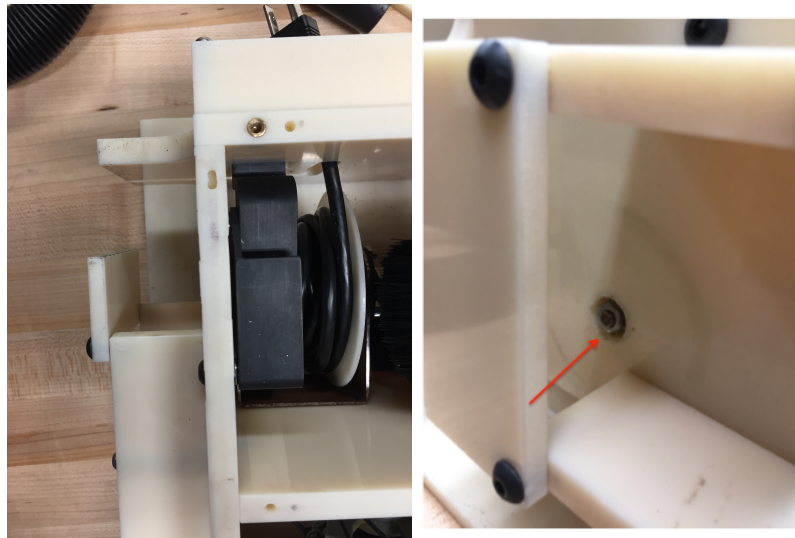


Figure 24: Shaft Length Failure

The next issue with the retractor involved the actual power cord configuration. The power cord was getting stuck on the walls of the body when it was trying to flow in and out of the retraction mechanism. Through further analysis, we discovered that the cord was traveling through a torturous path of corners, leading to undesired friction locations. For the prototype, we measured an appropriate length to minimize these interferences, and adjusted the hole accordingly. For the final design, this hole will be permanently relocated to minimize conflicting points of contact. Figure 25 shows the original torturous path, and the adjusted slot to accommodate for the cord.

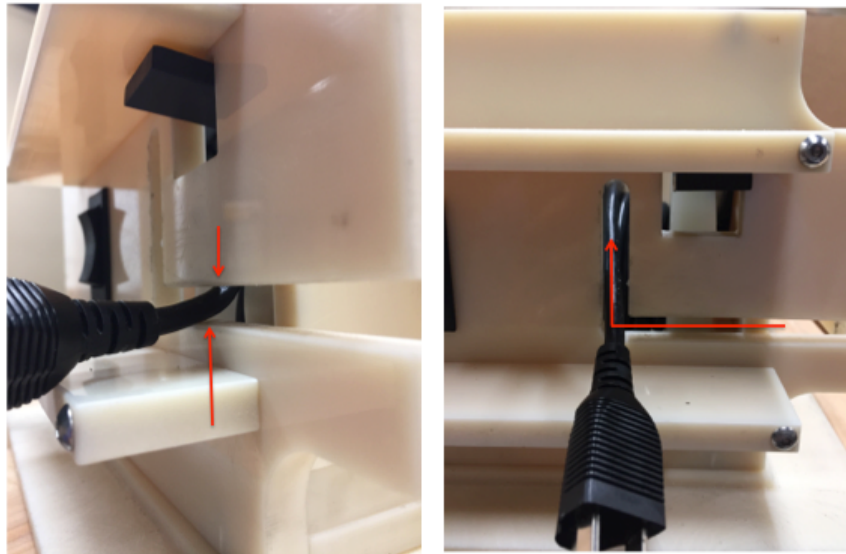


Figure 25: Power Cord Friction Failure

Similar to that issue, the retractor initially had trouble winding up the power cord. Through further analysis, we discovered that the original cord was much too thick for the spool and therefore too stiff to have proper winding capabilities. For the short and long term solutions, a smaller diameter, flexible cord will be used with this retractor. Figure 26 shows the current thin, flexible spring fitting nicely in the spool of the retractor.



Figure 26: Power Cord Diameter Failure

Power Switch

The failures found while putting together the prototype power switch together were each separate issues that withheld the power switching remote technology from operating correctly. Table 13 shows a full list of the power switch retractor issues, along with root cause analyses and solutions.

Table 13: Power Switch Failure Analysis

Problem	Root Cause	Short Term Solution	Long Term Solution
Lack of communication between electronic components	Transceivers not communicating as expected – no raw signal transmission	Replace constructed electronics with purchases remote switching kit	Purchase additional microprocessors needed to send/receive data packets via transceivers to operate power relay
Purchased electronics kit – circuit failed during testing – power source over loaded electronics circuit	- Components rated for power load - Circuit not compatible of handling power load for AC circuit - Supplier excluded important function details/ warnings	Call it a failure for prototype purposes	With more time..... - Find new supplier with AC capabilities, not limited to DC current power sources - Consult Lexmark electrical engineers to optimize original electronic

The first issue of the power switch involved a lack of communication between the electronic components. With further analysis, we discovered that the transceivers were not communicating as expected, which meant there was no raw signal transmission. If continuing to deal with this strategy, the solution would be to purchase additional microprocessors needed to send and receive the appropriate data packets through the transceivers to operate the power relay. However, given an extreme lack of time for this issue, we decided to approach a new strategy as a short-term solution.

The new strategy turned out to become the next failure. We purchased an electronics kit to allow communication between the handle switch and the main body switch. However, during testing, the circuit failed due to a power overload. Through further analysis, we discovered that the purchased components were rated for a certain power load, and the circuit was not capable of handling the power load of an AC circuit. While we lacked knowledge on this subject, we also lacked warning from the supplier in the function description of the parts.

Unfortunately, due mainly to lack of time, we had to consider this a failure. If we were able to work on this project for more time, we would first consult an expert on the matter. In talking to a professional electronics expert, we feel confident we could find a quick solution to our problem. Similarly, we would find new suppliers for our current electric parts in attempt to repair the failed attempts. In the future we will understand how important it is to research in incredible depth when working with equipment we are unfamiliar with.

While we encountered several failures in the process of building this prototype, we feel that we successfully addressed each issue and overall produced a satisfactory prototype design. The failures taught us how to analyze the root cause and approach solutions with an engineering mindset such that similar failures will not be repeated. Overall, the failure analysis phase of this project was arguably the most important part of contribution to our engineering knowledge base from this project.

Phase VIII: Ease of Use Testing

The ultimate objective of this project was to create a more user-friendly ink toner vacuum for the Lexmark facilities. Because this objective is subjective, we categorized user-friendly aspects through terms of vacuum operation. These aspects are the following: Convenient power cord storage, user friendly hose storage accommodating range of 2ft-6ft hoses, user friendly attachment storage, easily accessible power switch, easy to carry, easy to replace filter, and easy to clean.

To address most of these categories, and the general ease-of-use of the vacuum. We ran through a series of time trials using the old and new vacuums. For these time trials, we included team members and new users operating the vacuum. For these time trials, we used a basic process of operating the vacuum. Through this process the user would access and connect the hose and power cord, turn on the vacuum, switch attachments, then turn off the vacuum and replace all of the parts to their storage locations. Table 14 shows the time trials for the original vacuum, and Table 15 shows the time trials for the prototype. Figure 27 and Figure 28 show some photos of team members and new users running their timed trials.

Table 14: Original Vacuum Time Trials

Original Vacuum	Time Trial 1	Time Trial 2
McLean	1:22	1:21
Spencer	1:40	1:19
Treavor	1:33	1:27
New User 1	2:06	1:22
New User 2	1:51	1:35
New User 3	1:40	1:20



Figure 27: Original Vacuum Time Trials

Table 15: Prototype Vacuum Time Trials

Prototype Vacuum	Time Trial 1	Time Trial 2
McLean	0:31	0:29
Spencer	0:29	0:28
Rob	0:32	0:31
New User 1	0:38	0:35

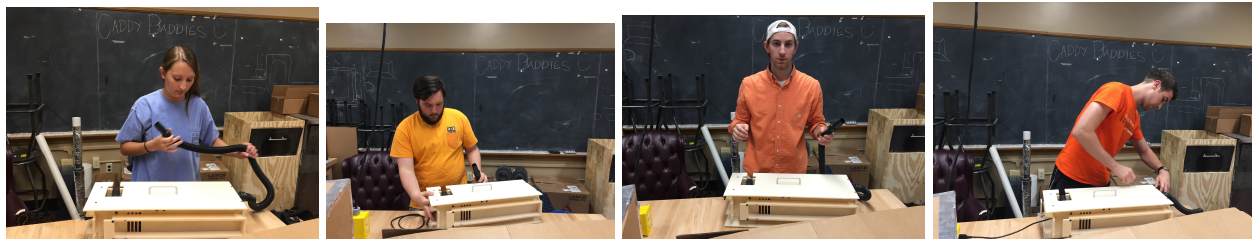


Figure 28: Prototype Vacuum Time Trials

As can be seen from Table 14 and Table 15, the time trials showed that the prototype vacuum cut the average time to operate the vacuum down to less than half of the original vacuum. This applied to both the team members and the new users. These tests showed that the new vacuum, while being used, is much more efficient and convenient for the user.

The other aspects of ease of use were analyzed through further use of the vacuum. The prototype power cord is stored conveniently through the use of a retracting mechanism instead of being tangled up in a bucket. Likewise, the prototype hose is stored along a convenient path along the side of the body, of which can accommodate hoses of various lengths between two and six feet. The attachments are similarly stored along the side of the body that makes it possible for a one-handed operation for attachment replacements. The power switch is still located in the same location, but with a more easily accessible switch. The vacuum has a handle on top, and required weight, width, and height dimensions that make it easy to carry. The filter may be changed easily through the removal of a few bolts to access the inside cavity of the vacuum. Finally, the vacuum is easy to clean because most of the mess is kept from entering the main cavity of the vacuum due to the outside storage of the hose and attachments. Overall, the use of the prototype vacuum has proven to be improved from the original vacuum, and therefore, our ultimate goal was reached with this design.

Phase IX: Final Steps

Senior Design Expo

At the end of the semester, our project was featured in the University of Tennessee Senior Design Expo. Here, we were able to present our project to the community as a working prototype. Unfortunately, we were not selected as winners for any of the contests within this fair. We assume this was most likely because the visiting community was more interested in the gory displays of other projects than our sophisticated vacuum project. If we were to participate in this fair again, we would have chosen to spice up our display by adding a more attractive or interactive aspects to the display. Figure 29 shows the poster we used to display our project at the Senior Design Fair.

Toner Vacuum Cleaner Caddy

Team Members: Rob Davis, Treavor C. Johnson, Erin McLean Miller, Spencer Sanders



Objective

Create a more user-friendly version of 3M toner vacuum for the Lexmark facilities.

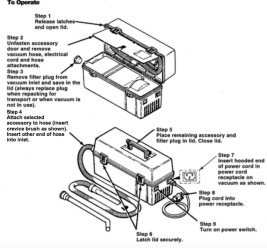
Improve:

- Equipment Storage
- Operation & Management
- Transportation Ease



 Dusting Brush Static Dissipative Used for applications involving static-sensitive electronic components such as circuit boards to prevent static buildup.	 Crevice Nozzle Static Dissipative Used for general cleaning of hard-to-reach areas. Prevents static buildup.	 Crevice Brush Static Dissipative Used with crevice nozzle for general cleaning of hard-to-reach areas. Prevents static buildup.	 Needle Nose Nozzle Static Dissipative Used primarily for cleaning circuit boards. Needle nose design permits cleaning in very tight areas, and static dissipative properties prevent static buildup.	 Curved Wand Nozzle Static Dissipative Used for general cleaning on hard-to-reach areas. Static dissipative properties prevent static buildup.
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To Operate



- Step 1: Remove batteries and open lid.
- Step 2: Unplug accessory and remove power cord and hose.
- Step 3: Remove floor plate from vacuum liner and slide in the lid. Clean up any dust or debris.
- Step 4: Attach selected accessories to the front. Insert other end of hose into the power switch.
- Step 5: Turn on power switch.
- Step 6: Plug cord into power receptacle.
- Step 7: Lock for security.

Design

Solutions:

- Create a 1-handed operation for attachment storage
- Create an easily-accessible slot for hose storage of any length
- Introduce a retraction mechanism for storage of the power cord
- Incorporate a power switching operation on the handle of the vacuum

Parameters:

- Weight of the vacuum must be limited to 14 lbs
- Width of the vacuum from the left to right side must be limited to 9 in
- Power switches must be located both on the body of the vacuum as well as on the handle for ease of use
- Vacuum must accommodate and self-contain a power cord up to a length of 6 ft
- Vacuum must accommodate and self-contain a hose up to a length of 6 ft
- Hose must be self grounded
- Vacuum body must incorporate easy access for filter replacement

Prototype

(Photos: 3D Model - bottom left, Constructed Vacuum - bottom right)

- Constructed mainly with assorted ABS plastic plates
- Incorporates slotted storage areas for each of the attachments that allow a 1-handed switching operation
- Incorporates slotted storage path for hose
- Incorporates newly designed retractor for power cord
- Incorporates desired switching mechanisms
- Allows for ease of filter replacement
- Required simple rework and manipulation of manufactured parts to fix minor assembly issues



Next Steps

Optimize prototype design to finalize a thermoform vacuum design using the tested and approved prototype dimensions. The thermoform technique was chosen for ease of creation and expense. This task will help deliver a final product that reaches our goal of low cost manufacturing and mass production








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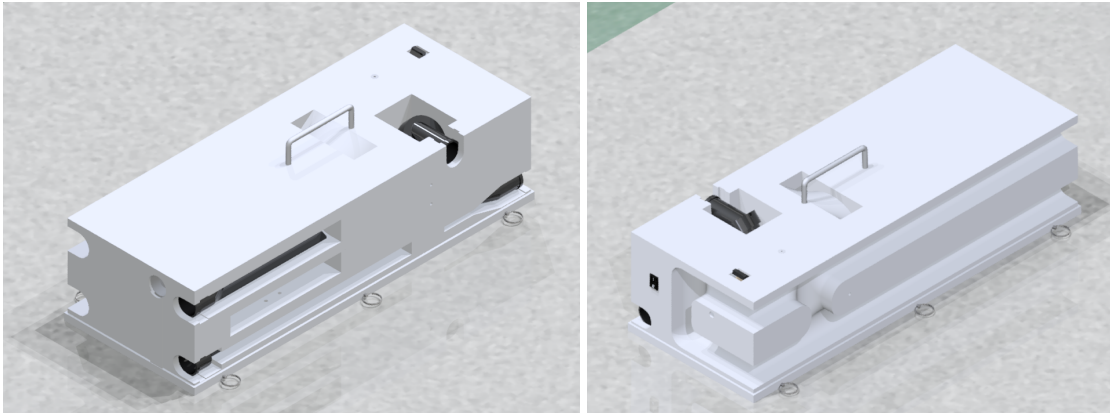
Faculty Sponsor: Steve Foster
Industry Sponsor: Lexmark, Inc., Dave Merrifield

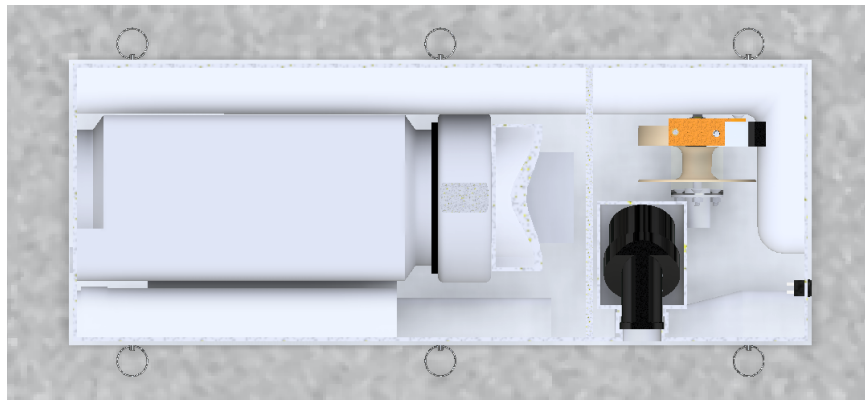
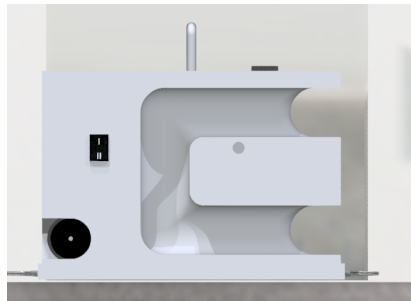
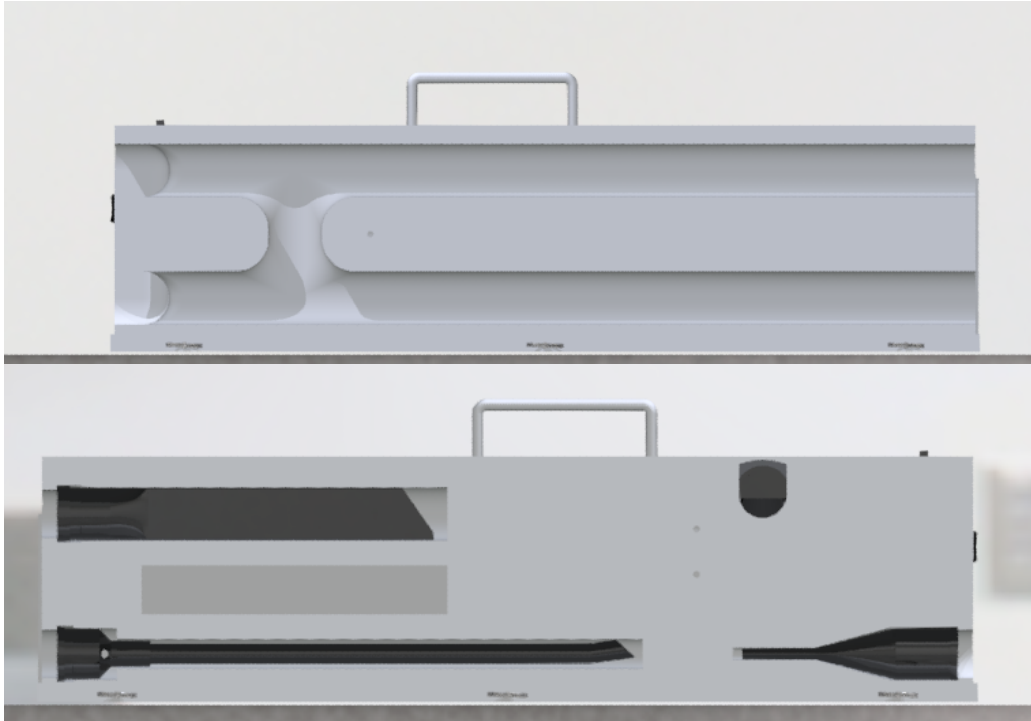



Figure 29: Senior Design Fair Poster

Final Design

The final design represents all the changes that were made to the prototype model in a vacuum formed design to reduce cost. The new design will feature one handed attachment removal; however, it will not have magnets to positively lock the attachments into place because we found through experimentation with the prototype that the friction hold between the attachment and body plates was more significant than the holding power of the magnets and was more than necessary to hold the attachments into place. The motor lock was also replaced with a draw to reduce the amount of parts and variation in the design. The method for mounting the retractor was also modified to be mounted from the bottom to alleviate some of the slipping issues with the shaft that were found during the prototyping process. The body also has a quick remove feature for the body to the bottom plate to ensure that the filter can be accessed quickly. **Figure** shows screenshots of the model of the final design.





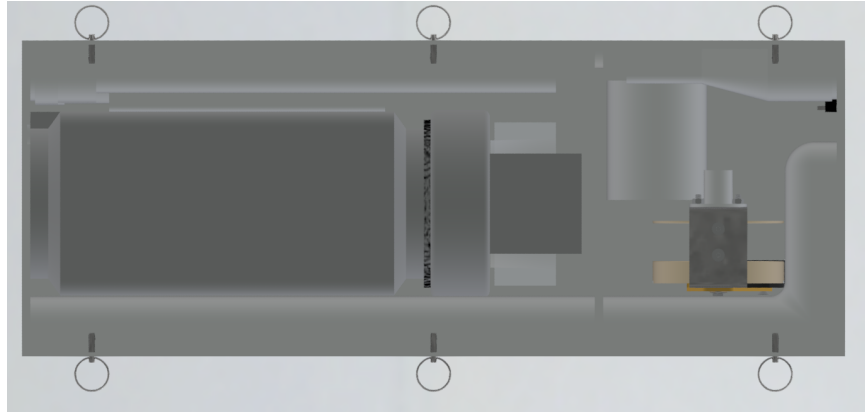


Figure 30: Final Design Models

For the cost analysis of this vacuum, we summed all of the prototyping costs for production of the prototype retraction mechanism. For our final design, per Dave's recommendation, machining cost was assumed to be half of the prototype machining. For purchased components, we used the bulk price of 100 plus units if given, and to calculate the cost, we used the ratio of what we used within building. For example, if the cost of the package of screws was a certain price, but we only used half of the screws, we prorated those costs for the analysis.

For the body, we assumed we could fit 4 of the vacuum formed parts on to a single 4x4 sheet. This would require 5 hours of machine time to make 100 units, because they are capable of running 5 sheets and hour at \$210 per hour. Cost to machine a mold was \$350 each, and mold materials were \$15 each, coming to a total of \$2510 for machining and tooling of the vacuum formed part.

We assumed machining for the middle plate would cost about the same for the middle piece of the vacuum, but we were unsure of the cost of the bottom, because we were unable to communicate this clearly with the machinist given our time.

Further detail concerning pricing and analysis for the retractor can be found in Figure 31. Similarly, further detail concerning pricing and analysis for the whole body can be found in Figure 32.

Part	Prototyping Cost	Estimated Production Cost	Estimated production of 100 units
Spool	250	125	12500
Arm	218	109	10900
Shaft	80	40	4000
Spring Holder	160	80	8000
Wheel	80	40	4000
Lever	375	187.5	18750
Slip Ring Mount	210	105	10500
Total			68650
Per Unit			686.5

Purchased Components	Qty In Package	Package Price	Qty Needed	Qty Needed for 100 Units	Price for 100 Units
Flanged ball bearing	1	9.64	1	100	964
M6 button head	50	9.64	1	100	19.28
Thrust Bearing	1	3.49	1	100	349
Slip Ring	1	16.77	1	100	1677
Thread Inserts	25	7.39	4	400	118.24
M5 Flat Head Screw	50	6.42	7	700	89.88
M5 Hex Nut	100	1.73	6	600	10.38
Compression Spring	12	7.26	1	100	60.5
Internal Tooth Lock washer	10	2.21	1	100	22.1
.16x8x3500 mm power spring	1	5.45	1	100	545
M3 hex cap screw	100	8.21	1	100	8.21
Power Cord	1	3.88	1	100	388
Low profile M5 16mm long	100	7.75	2	200	15.5
Total					4267.09
Per Unit					42.6709

Total Per Unit Cost:	729.17
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Figure 31: Retractor Cost Analysis

Body occupies 620 x 234 mm (24x9)	Vacuum form cost per hour	Hours to make 100 units	Mold Materials	Mold Machining
	\$210	10	30	700

Vacuum form Production Cost:
\$2,830.00

Purchased Components	Qty In Package	Package Price	Qty Needed	Qty Needed for 100 Units	Price for 100 Units
Handle	1	4.2	1	100	420
Switch	10	3.15	1	100	31.5
Quick Release Pins	1	1.53	6	600	918

Materials	
1/8" Sheet for body	3725
1/4" plate for middle	421.5
3/8" plate for bottom	2519
Machining of middle plate x100	12250
Machining of bottom plate	??
Total Cost for 100 Units	Cost Per Unit
\$23,115.00	\$231.15

Figure 32: Body Cost Analysis

Conclusion

The project we were assigned at the beginning of the year was to design a simple vacuum cleaner caddy. By learning about Lexmark through our company sponsor, Dave Merrifield, and our senior design professor, Steve Foster, we have been able to visualize the importance of our final product in the Lexmark environment.

During the first semester, we began by setting a goal to create a user-friendly vacuum. We established this goal by defining what aspects of the vacuum required improvement to increase ease of use. Then, through extensive research and brainstorming, several improvement options for each aspect were found. Design modifications were then created based on this research. Concepts proven successful from the modified designs were then combined to create a progressed design that was intended to be developed during the second semester.

Moving into the second semester of the project, we were faced with the task of reviewing our prototype design, creating and ordering parts for all parts of the prototype, and putting together the ordered parts, analyzing failures in the design, and finally creating the working prototype for the presentation. After months of hard work going into each of these steps, the prototype is ready to be presented to our professor, as well as our corporate sponsor.

We achieved our goals of creating a more user-friendly vacuum for the Lexmark facilities and are excited to present our product to the appropriate audience. If we had more time to work on this vacuum, however, we would fully indulge ourselves in the advancement and improvement of our current prototype by having our final design model manufactured through Lexmark. The final design would meet all criteria not met so far, and would improve on the issues found through the failure analysis phase of this process.

We were originally given a task to create a new vacuum cleaner caddy, but throughout the process thus far we have gained so much more than just a working prototype. We have learned so much more about the engineering design process, and all of the miniscule, yet critical components that are required for a successful solution. While we have accomplished a lot thus far, we know we have so much more to learn and gain from the engineering world now that we have been through this course. Having gained some wisdom, we are excited to put forth the effort after graduation to expand the knowledge we have expanded through this process and continue strengthening our minds as engineers.

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Appendices

Appendix A: Project Expectations Document

Product	Expectations	Revision A, 9/27/16
1) Hardware		
a) Working vacuum with following qualities		
i) Easy to carry	(1) Weight will be kept below 14 lbf (6.35 kgf) (2) Caddy will remain at or below 9" (22.86 cm) in the dimension perpendicular to the body	
ii) Convenient and user friendly switch	(1) Switch will be moved from back of machine to a more convenient location or an alternative method of switching will be used	
iii) Cord storage	(1) Cord will be self-contained and capable of reaching at least six feet	
iv) Hose storage	(1) Hose will be self-contained and capable of reaching at least six feet (2) Hose will be grounded	
v) Attachment storage	(1) Attachments will be easy to store and retrieve (2) Attachment storage will limit chance of losing attachments	
vi) Easy to replace filter	(1) Final design will not decrease ease of current filter removal	
vii) Easy to clean	(1) Small crevices will be limited to reduce chance of loose toner buildup (2) Product material will not show grime	
2) Documentation		
a) All necessary documentation to reproduce design		
i) Every member will create at least one drawing		
ii) Assembly drawings		
iii) Component drawings for all created parts		
iv) Purchased components list		
b) Tolerance analysis for fit and function		
c) Calculations		
i) Stress		
ii) Deflection		

Appendix B: Gantt Chart

Appendix C: Parts Drawings