FINAL REPORT

EML4550C – Senior Design Spring 2016

TEAM 17 - "IMPROVED DOG GROOMING TOOL"

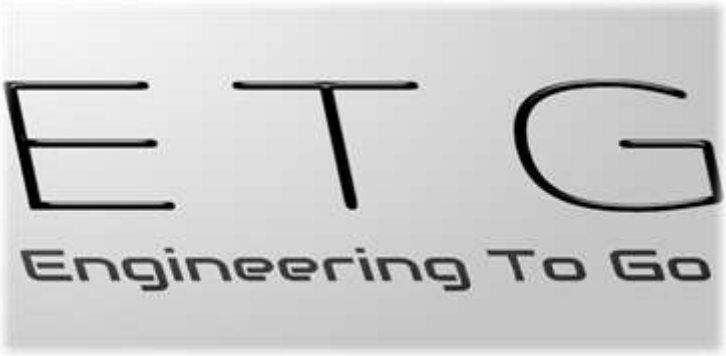

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Table of Contents

Table of Figures

Team Biography

Justin Proctor is the team leader of Team 17. He is also an active member of the student chapter of Society of Automotive Engineers, were he serves as the head of the Baja Racing rear suspension unit. In his spare time Justin enjoys working on white Mazda Miata as a project car.

Jordan Chupp is the Team Secretary for Team 17. He is in charge of making sure that all notes are taken and that all minutes from any meetings we conduct are recorded. Justin is into archery as he likes going out to shoot his crossbow

Dennis Pugh is the Treasurer for Team 17. He is the head of managing our accounts, how much we have spent and what we have to spend. He is also in charge of submitting and keeping record of receipts, invoices, and any purchase orders. Dennis is a member of the Florida A&M University's Track and Field team.

Roy Mason is Team 17's Web Designer and Editor. He is responsible for editing and creating the layout of Team 17s webpage, as well as formatting, editing, and finalizing all reports and presentations for submission and use. Roy Mason is an active member of the Florida State University chapter of the Society of Automotive Engineers, were he serves on the executive board as club treasurer. He is also a part of the Baja Racing brake design unit. Roy Mason enjoys pencil sketching, playing basketball, and studying the Bible.

Acknowledgements

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Team 17 would like to thank Dr. Simone Hruda, as she is the faculty advisor for Team 17. Dr. Hruda has been very helpful to Team 17 through her advice and council concerning key steps that were nearly missed and the acquiring of resourceful information that allowed Team 17 to gain a better understanding of what tasks need to be accomplished

Team 17 would also like to give thanks to Dr. Nikhil Gupta as well as Dr. Shih, for their continued guidance, evaluation and constructive criticism. Dr. Gupta and Dr. Shih have helped motivate Team 17 to stay on task and to have good schedule management.

Team 17 would like to express in gratitude to its team sponsors, William Billbow and Todd Hopwood. Team 17 is grateful for them for providing them with the opportunity to even embark on this project by being the first team to be a part of their engineering entrepreneurial incubating initiative. Team 17 would like to thank them for their support both financially and through the preliminary design and planning process.

A special thank you from Team 17 to all those who participated in the consumer survey, with a major thanks to the Lori Williams at Paws and Claws for her willingness and openness to participate in the research and testing and trial phase.

Abstract

Dogs are known as man's best friend, and just like man dogs require constant grooming and caretaking, in order to remain happy, healthy, clean, and pain free. The current process for which dogs are groomed are primarily through bathing, brushing, and shaving. The process of grooming certain dogs with various fur textures and lengths can be very tiring, strenuous, and unpleasant for the dog and the caretaker. For these reasons as well as a hectic busy lifestyle, many owners do maintain a consistent grooming regime for their dogs and so tangles in the fur and mats develop. The process of dealing with mats is much more difficult than regular brushing of a dog and so many owners give them to groomers who must then go through the taxing process of mat removal. Regardless of if it is a groomer or owner the grooming process for a dog can become hard work and a nightmare. This project tackled this issue by developing a rotary brush tool that looks to prevent mats forming by taking the pain out of brushing and encouraging dog owners and pet caretakers to brush their dogs more. The rotary brush tool was successfully developed, and this report presents the process, challenges, decisions and designs used to create this grooming solution.

1. Introduction

1.1. Problem Statement

For this project we have two sponsors, Todd Hopwood and William M. Bilbow. The problem presented to Team 17 is that dogs of all hair qualities, textures, and lengths, experience matting and tangling in their coats. This matting makes it tough to groom the dog when trying to complete small tasks, such as brushing a dog's hair. This problem is seen in many different types of dogs with different hair lengths.

"De-matting a dog's hair can be an unpleasant experience for both the dog and the groomer, especially if the matting has advanced and is deep in the hair or fur. To de-matt or de-tangle, it can be very time consuming and uncomfortable, if not painful."

1.2. Goal Statement and Objectives

The overall goal of this project was to design and develop an electrical grooming tool that provided both the user and dog with a pleasant, stress free, time efficient grooming experience. The tool was to decrease the effort required to untangle, de-mat, and smooth dog fur while remaining as, or more effective than current manual tools.

1.3. Project Constraints

The constraints of this project are:

- The tool must be hand-held and ergonomically friendly
- The tool must have a low RPM to keep quiet
- The tool must be easy to clean and sterilize
- The battery should last 2 hours at 50% duty cycle
- The total weight must be at 1 pound or under

1.4. Requirements

1.4.1. Design

In order to design a tool that will met the specified goals, various specifications are required. Table 1 below lists the design specifications, but they are broken down here with descriptions starting with the overall design. The whole tool must be lightweight, which will require it to be one pound or less. The design will also need to be visually appealing in order to

get customers to buy the product when it hits the market. The design of the tool itself can be broken down into three major components which are the handle, the internal electronics such as the motor, and the rotary head.

Starting with the handle, it must be hand held and ergonomic, meaning the device must be comfortable to the customer's hand and not much force be needed to operate the device. The idea is to take away as much stress as possible and by providing a customer friendly tool, much stress will be levitated.

Moving to the inside of the tool, the battery will need to have a 2 hour duty with an 8 hour standby. Along with these specifications, the battery must be designed to be replaced quickly. The more stressful it is to replace a battery the less likely someone is to buy the product. Also, the power must have 120V AC charging capacity. These specifications are early on and are subject to change if needed.

Finally, there are some rotary head specifications. These include removable, single speed, bi-directional, low speed, small diameter, and bristles. The removable idea is key, because if one head is ruined, instead of replacing the whole tool, one could just replace the head. Also, taking the head off the tool provides a much easier availability to clean the head. The device must be single speed so that a careful low speed near 60 revolutions per second would not harm the animal. The bi-directional does not mean go both directions in this case, it refers to the head being able to be put on in the opposite direction so that no matter which hand is dominant the customer has the same experience. Lastly, the head specifications include being around 1.5 inches in diameter, as to not be too bulky, and to have bristles of some kind that are not corrosive and easily breakable. These bristles are not required to be of a certain material. Many different types will be thought of and the type that is most successful when dealing with efficiency and harmless to the animal will be chosen.

1.4.2. Performance

When designing this dog-grooming brush there are many performance specs that have to be taken into account. The performance specifications will define the desired functionality of the product when being used. With the understanding that dog groomers, dog rescue workers, and personal dog owners will be using this product, it is essential that the performance of this dog-grooming brush meet the needs and expectations of every consumer.

Some of the main performance specifications that this product must meet are that it must be able to detangle and de-mat any type texture or length of dog. From talking with many dog groomers, rescuers and dog owners, it is very apparent that detangling a dog's matted hair is very frustrating. It is said that using a conventional dog grooming brush is very time consuming, which is why we are creating a rotary style grooming tool. The brush must be electric powered device that does the de-matting and detangling work for the user. The brush must reduce the time it takes to de-matt a dogs coat significantly enough to make the use of Team 17's product worthwhile to customers.

Dog groomers and owners claim that using a conventional dog grooming tools create a lot of stress on the hands and arms of the groomer. The electric functioning of the brush must perform in a manner that reduces the wear and tear on the user, and eliminates the stress that dogs experience when the groomed manually. Team 17 has to make the tool more ergonomic to appeal to the comfort of the person using the brush. By creating an enjoyable experience with a simple task of grooming for the dog and its groomer, Team 17 can build brand trust and healthy consumer producer relationship.

The brush design must perform as quietly as possible, and output enough work to be effective in its grooming task while not harming any dog during the process.

2. Background Research

After some rigorous researching current solutions to issues with tangled and matted dog fur, it was found that there are many types of dog grooming tools that are on the market today. One of these tools include the FURminator, seen below in Figure 1, which is said to reduce shedding by up to 90%. This tool is widely popular with dog owners and some but not all groomers and has established a reputation of being expensive but the best option as far as dog grooming tools. The FURminator was not design to deal with mats due to its finely spaced teeth, and so its uses for grooming are limited. Another tool widely used, mainly by groomers, is a mat-splitter, shown in Figure 2. This tool is used strictly for breaking up deep mats that occur close to the skin of the dog and bring them to the surface of the fur to be brushed out. This tool isn't widely owned by dog owners, and so when advanced mats do develop, most owners will try brushing the dog, shave the dog, or hand it off to a groomer. Mat splitters are effective at the job, but their open blades pose hazards for dogs and people when handled by an unskilled user, and they require a lot weary manual labor to operate. Another tool just happened to come to the market within the last year and

is known as the Knot-Out, Figure 3. The knot out is an electrical wide toothed comb that houses disk blades in between the teeth. It is design purpose to smooth dog hair and as a mat or tangle is encountered, a button is pressed which activates the blades that are meant to spin and cut through mats. This tool is very similar in idea to what Team 17 is develop, but is far in design and function. The Knot-Out is noisy and is cheaply made. The wide toothed layout out is unideal for thin hair dogs, and its overall comb covers but a small surface area, leaving the user to have to use it for extended periods on larger dogs.

Figure 1: FURminator

Figure 2: Mat Splitter

Figure 3: Knot Out

The tools discussed from the research have their positives that work for them, except the Knot Out which is purely just a negative. Team 17 took time to evaluate what these tools lacked in from a funtional andd ergonomics standpoint and looked too imrove upon them while achieving the goals. Table 1 below illlustrates the background analysis done on the three tools

Table 1: Background on Current Tools

Tool	Price	Function	Issues
FURminator	$20 – 60	• Combs through dog coat to manage shedding	• Expensive • Cant be used with tangles and mats present
Mat-Splitter	$ 5 – 11	• Breaks up mats by longitudinally splitting hair	• Can be dangerous to dogs and inexperienced users
Knot Out	$15 – 20	• Catches mats as tool combs through fur. • Inner blades rotate to break up mats • Electrical Tool	• Small surface area and thick teeth minimize coverage in one stroke • Cheap, Loud, Scares Dogs

2.1. Voice of the Customer

In the preliminary stages of this entrepreneurial project, it was necessary to go out and identify the target customers, and understand what their experiences with the current dog grooming tools were, and whether or not our solution was something of interest to them. Team 17 understood that the creation of the product would not matter if no one wanted it, or if it did not meet the needs of the users. With the voice of the customer, Team 17 was not only able to determine the relevance of the project, but also what the grooming tool would need to accomplish in order to be considered an improvement from what is currently being used. To obtain the voice of the customer Team 17 conducted an online survey, as well as one on one interviews with dog groomers, owners, and caretakers. Table 2 below shows the type of questions that were asked in the survey and the interviews as well as a statistical summary of the responses from given from the people.

Table 2: Voice of the Customer Results

Questions	*Results*
What is your age?	60 % of Surveyors were 18-30
Describe your dog's coat	55% said dog had thick coats, majority were medium in thickness and medium in length 64% surveyors deal with shedding
What tools do you use for messy dog fur	50% use some sort of brush (fine tooth, slicker, plastic)
How often do you brush your dog	46% brush their dog at least once a week
How do you find the grooming experience	55% don't like grooming their dogs and/or t is a lot of work
How long does your tool typically last	100% at least 6 months
How does your dog respond to being brushed	45% claimed that dog does not enjoy it or is uncooperative
Rank Tool Selecting Factors	1st place: Price (32%) Shape and Design (23%) 2nd place: Past experiences (28%) Materials it's made of (18%) 3rd place: Special Features, Low Maintenance, Past Experiences (14%)
How much would you be willing to pay for an improved tool	86% of surveyors will pay at least $20-$30 for a better tool

2.2. House of Quality

Figure 4 shown above is the House of Quality for Team 17. This diagram was constructed based on results from surveys and questionnaires that were conducted in order to define the voice of the customer. The house of quality was used to form relationships between the desires of the target market and engineering characteristics of the dog grooming tool. The engineering characteristics are grouped under the categories of the tool's mechanical performance, technical specifications, and the user friendliness. All the categories except for the user friendliness are quantitative categories, which require the application of mathematical calculations and engineering

principles. The user friendliness is a qualitative measurement and will be in direct relation to the voice of the customer. The roof matrix interrelates the engineering characteristics with each other define those that have strong, medium, and weak correlations. Finally the customer importance ranks the customer requirements on a 1-5 scale, with 5 being most important and 1 being the least. The planning matrix is similar to the customer importance as it likewise ranks the importance of the same customer requirements for team 17 and the designs of the leading competing devices

(+) – Positive Correlation
(-) – Negative Correlation

◊ - Strong Interrelationship
□ - Medium Interrelationship
○ - Weak Interrelationship

Rankings are on a scale of 5 to 1 with 5 being the most important

Direction of Improvement		↑	↓	↑				↓	↑		↓		↑	↓			
Engineering Characteristics / Customer Requirements	Customer Importance	No. of Brush Head Blades	Brush Head Angular Velocity	Brush Head Output Torque	No. of Brush Head Motors	Brush Head Materials	Brush Electric Power Source	Total Brush Size	Multi-Sized Brush Heads	Meets Safety Standards	Weight	Brush Handle Materials	Ergonomic Handle	Brush Noise	Team 17 Product	Furminator	Mat Splitter
		Mechanical Performance				Technical Specifications						User Friendliness			Planning Matrix		
Affordable Price	5	◊			◊	◊	□		□		○	◊			4	2	1
Comfortable Grip	5							○			○	◊	◊		5	2	1
Simple to Use	3	○					◊		□				◊		4	4	2
Minimal Effort to Use	4	◊	○	◊			□	□	◊		◊		○		5	2	2
Non-Stressful for Dog	5		◊	◊		◊				◊	○			□	4	2	4
Works with Various Hair Types	3	○		□		○			◊						4	3	2
Disposes of Hair	1	○	□					◊							2	1	1
Longer Handle	1							◊			◊	○	◊		1	1	1
Durable	2	□				◊	○	○			□	◊			4	5	4
Removes Mats from Dogs	5	◊	□	◊		□			○						5	3	3

Figure 4: House of Quality

3. Concept Generation

3.1. Concept Design One

Since the initial goal of this project was to make a simple, hand held product, design one focuses on these qualities and attempts to be a product that will appeal to multiple audiences. This

as seen in Figure 5, below, this design is as simple as possible while meeting all of the project constraints set by the group and sponsors. It has a very simple handle with a motor driven brush head.

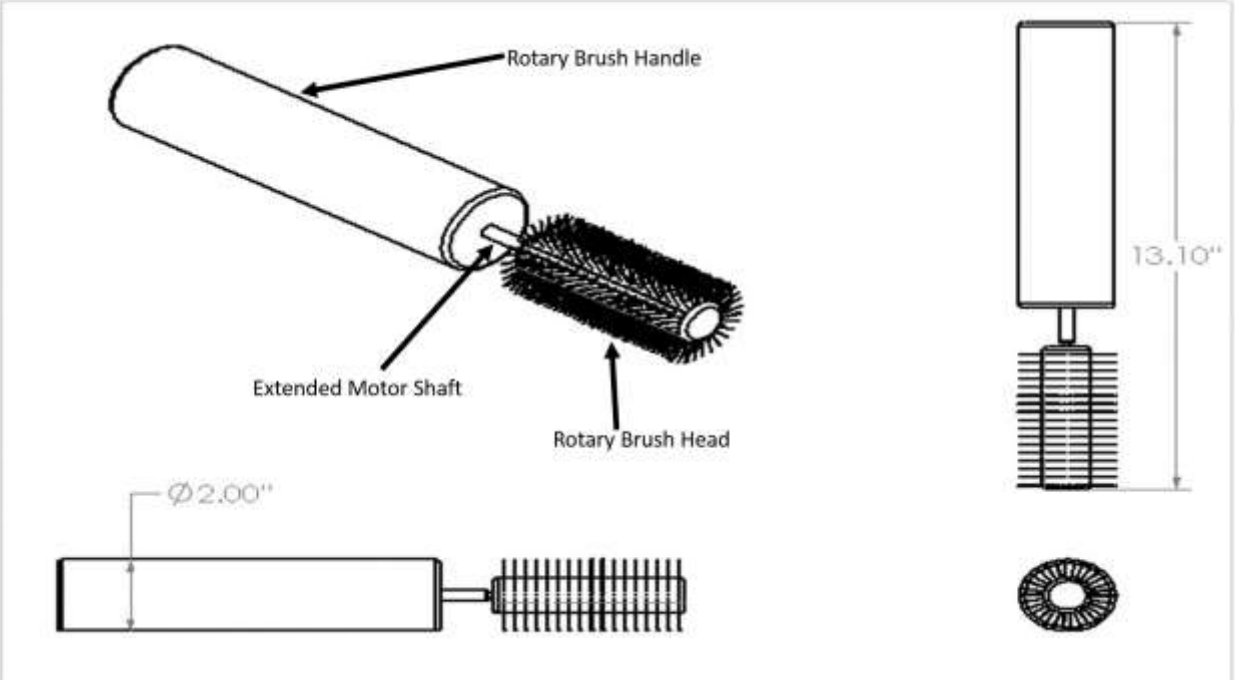


Figure 5: Concept Design One

Design one, or the hairbrush style, is designed to be familiar looking to the general public. This familiarity should help when introducing the product to potential customers. Not only is the handle oriented to make use very natural, the steel wire bristles used in the brush head should be able to easily pull matts out of thick hair, with nothing more than normal brushing movements.

While design one is designed to very simple to use, it does have some drawbacks. The number one concern, as with any project, is safety. For this product to be sold commercially, safety must be a major design factor. To ensure no harm will come to the animal being groomed, it may be necessary to install guarding or bumpers around the brush head. There is also a chance for longer hair to become tangled around the barrel of the brush. This can be prevented by keeping the barrel sufficiently large so that even the longest of hair cannot fully wrap around it.

Design one also has drawbacks in terms of ergonomics. Although the brush was designed to be simple to operate, it does lack some key features that would make it easier to use for some users. Most notably, it lacks ambidexterity. Due to the rotation of the brush head, it would not be possible

for left handed users to use the brush as comfortably. In order to solve this, the motor would need to have the ability to run in the reverse direction. While this is not a terribly complicated feature to add, it still requires more weight and planning to include. Table 3, below, includes a list of the pros and cons for this design.

Table 3: Concept One Evaluation

Pros	Cons
Simple Handle Design	Lacks Ambidexterity
Low Cost to Manufacture	Requires Motor Reverser
Easily Swap Brush Heads	Difficulty Assembling Wire Brush Head

3.2. Concept Design Two

The second concept design that Team 17 developed incorporates the familiar style that is commonly seen in a 2" paint brush. The design consists of an ergonomically shaped handle that will be designed to contour to finger placement as shown in Figure 6. Concept design two's handle will require that the user hold the handle in a vertical orientation shown below in Figure 6 versus the horizontal hand placement that concept design one requires in Figure 5. Based on research of grooming techniques it is understood that a vertical brushing motion will cause muscle fatigue more quickly than the horizontal motion. However, due to the fact that the brush will be motorized, the energy normally exerted by the user during repetitive brush strokes will be unnecessary. The brush head design concept was initially set to be cylindrical, having 8 inches in length and 4 inches in diameter. The design goal behind the 8 inch long brush head was that a longer brush head would cover as much dog hair surface as possible in order to limit the amount of time it takes to groom the dog. As far as the mechanical features of the brush tool in its entirety, they will be determined and chosen after further component and motor research and analysis are conducted. Table 4 below indicates the initial pros and cons that are associated with concept design two. One benefits that concept design two provides is the ergonomic handle. The fact that there does not need to be a reversible motor for the brush head to rotate for the use of left handed and right handed users is desired. Another benefit is the fact that this concept is designed to keep all motors and electronics in the handle, allowing the brush head to be as simple in design as possible, making it cheap to replace and interchange. Drawbacks of this design are that the open spinning brush head could pose a danger to users who are ignorant or careless, and that it is currently unknown as to whether this design will be the best option in housing all essential components.

Table 4: Concept Two Evaluation

Pros	Cons
Ergonomic Handle Design	Could be complex to fabricate
Provides for ambidexterity	Open spinning could be hazardous
Easily Swap Brush Heads	Unknown whether all necessary components can be housed

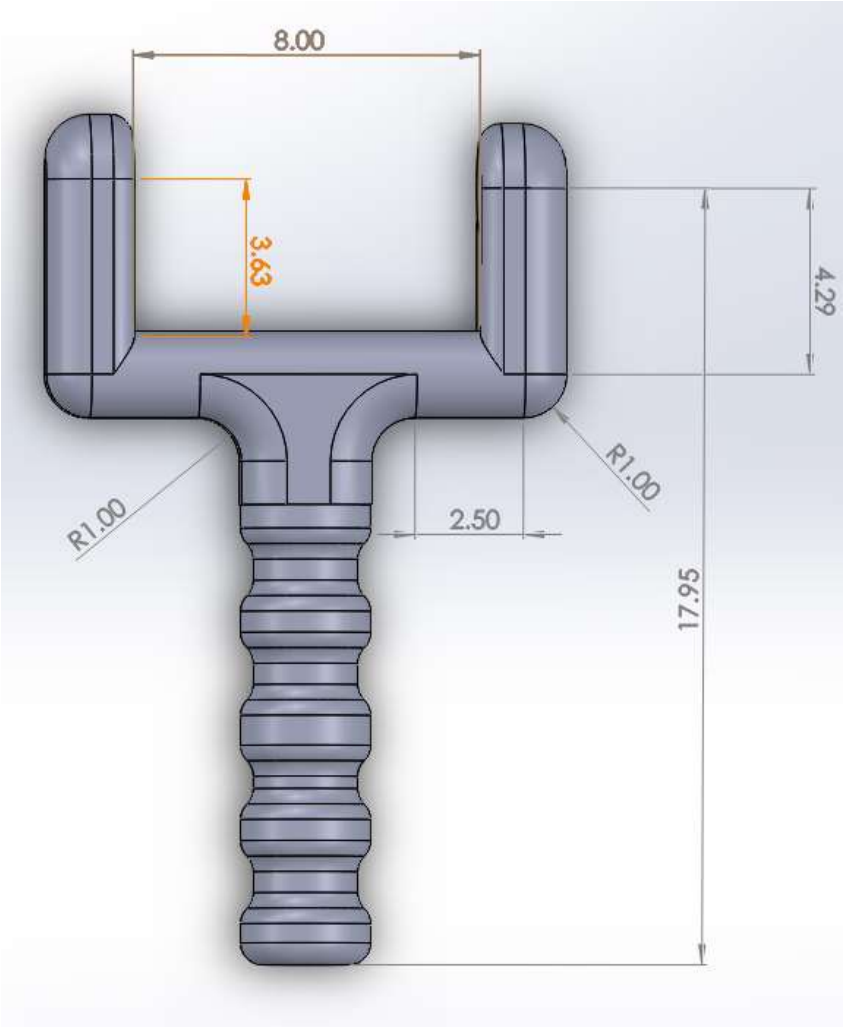


Figure 6: Concept Two

3.3. Design Selection

When it came time to choose the final concept design, a great effort was made to make an unbiased decision and choose the best design criteria available. By creating decision matrices for the various components up for selection, it was possible to rank the choices based on a number of

different criteria. Doing this allowed the team to determine the best options and create the best prototype possible.

3.3.1. Motor and Power Selection

The first component to be decided upon was the motor and power source that would be used to turn the brush head. Knowing these components would allow the handle to be designed, to ensure there would be adequate space to house all of the necessary equipment. Referring back to the original project constraints, the team knew that the motor would have to spin at a relatively low rpm and the power source would need to last at least two hours. Keeping these constraints in mind, the selection of motors was focused to ones whose speed would be between one and two revolutions per second. Since battery longevity was a key constraint, 110V AC current was considered due to the removal of the battery pack which would not only extend run time, but weight would also be saved. Three motor and power options were considered for the final concept: AC powered motor, DC battery powered motor, and AC converted to DC power to do away with a battery pack. Table 5, below, shows the results of the decision matrix.

After analyzing the motor decision matrix and tabulating the results, it was found that the ideal choice for the prototype would be a DC motor power by converted AC power. The decision factors used in this matrix were power, user safety, reliability, cost, weight, and pet safety. The winning selection received high marks in the safety, cost, and weight categories, beating out the battery powered DC motor by six points. By doing away with the heavy and expensive battery pack, the winning selection was able to beat out the other two options.

Table 5: Motor and Power Decision Matrix

Decision Factors	Column1	Choice 1	Choice 2	Choice 3	Scores	Column2	Column3
Criteria	Weight (1-5)	AC Motor	DC Motor	Battery Powered DC	AC Motor	DC Motor	Battery Powered DC
Power	3	5	4	3	15	12	9
User Safety	5	3	4	5	15	20	25
Reliabilty	3	5	4	3	15	12	9
Cost	4	3	4	3	12	16	12
Weight	3	4	5	3	12	15	9
Pet Safety	5	3	4	5	15	20	25
				Total Scores	84	95	89

3.3.2. Brush Handle Material Selection

The second decision matrix created aided in determining the best material for the handle. While there are countless material options from which brush heads can be manufactured, project goals stated that the handle must be ergonomic and comfortable for the user. Not only does weight play a large role in this decision, the material must also be pleasant to hold for long periods of time. The team also determine that the handle material should be somewhat slip resistant since many grooming tools are used on wet animals. The final options were narrowed down to three options. Choice one was aluminum, which was chosen because of its strength, fairly light weight, and ease of machinability. The second choice was ABS plastic. ABS has a high strength to weight ratio and can also be 3D printed quite cheaply. The last option chosen for the decision matrix was HDPE plastic, which is the most common plastic used in manufacturing. Table five shows the handle decision matrix and criteria the chosen material was based upon. As can be seen from the decision matrix in Table 6, the material best suited for the prototype handle is ABS plastic. This material scored high in manufacturability, user safety, and cost. ABS will be the ideal material for prototyping the design because it can be 3D printed quite cheaply and can handle all of the stresses and abuse the brush will encounter

Table 6: Brush Handle Material Decision Matrix

Decision Factors	Column1	Choice 1	Choice 2	Choice 3	Scores	Column2	Column3
Criteria	Weight (1-5)	Aluminum	ABS Plastic	HDPE Plastic	Aluminum	ABS Plastic	HDPE Plastic
User Comfort	4	3	4	4	12	16	16
User Safety	5	3	4	4	15	20	20
Strength	3	5	3	4	15	9	12
Cost	4	3	4	4	12	16	16
Manufacturability	4	4	5	4	16	20	16
Weight	3	3	5	4	9	15	12
				Total Scores	79	96	92

3.3.3. Bristle Design Selection

The last prototype design criteria to be decided upon was the bristle design. Once again, three final options were used in the decision matrix. These options included metal wire bristles, plastic bristles, and metal blade style bristles. Ranking criteria included safety, comfort and performance. The decision matrix for the bristle selection can be seen in Table 7. In Table 7, the winning bristle design was the metal wire type. This option excelled in the reliability, manufacturability, and user safety categories. This style of bristles will be make out of 0.01” stainless steel wire for added reliability and reduced corrosion. Although the metal bristles were the overall winner, the plastic bristles were a close second. Plastic may still be another bristle to test if the metal bristles do not perform as expected.

Table 7: Bristle Material Decision Matrix

Decision Factors	Column1	Choice 1	Choice 2	Choice 3	Scores	Column2	Column3
Criteria	Weight (1-5)	Metal Wire Bristles	Plastic Bristles	Metal Blades	Metal Wire Bristles	Plastic Bristles	Metal Blades
User Comfort	3	3	4	1	9	12	3
Pet Safety	5	4	5	1	20	25	5
User Safety	5	5	5	1	25	25	5
Pet Comfort	5	3	4	2	15	20	10
Reliability	3	5	2	2	15	6	6
Dematting Performance	4	4	3	5	16	12	20
Cost	4	4	4	3	16	16	12
Manufacturability	3	4	3	1	12	9	3
				Total Scores	128	125	64

4. Testing and Analysis

In order to determine how well the primary selected brush components such as the motor, the brush head, the bristles, the motor shaft adapter, and the handle would perform, various tests and analyses were conducted. Material that was used to conduct these tests were string, faux alpaca fur, the fur from a dead fox, cat fur, and real dog fur. The devices that were used to collect the data were a spring scale, a ruler, and a digital caliper. With the results of the tests, Team 17 was able to conclude whether or not specific selected brush components remained suitable for inclusion in the brush design or if the team needed to go with a different option.

4.1. Motor

4.1.1. Motor Stall Force

This motor stall force test was conducted to determine the maximum applied reaction force that the motor could endure before stalling. The materials used to carry out this test were the brush without the head attachment, a piece of string, and a spring scale, all shown in Figure 7.

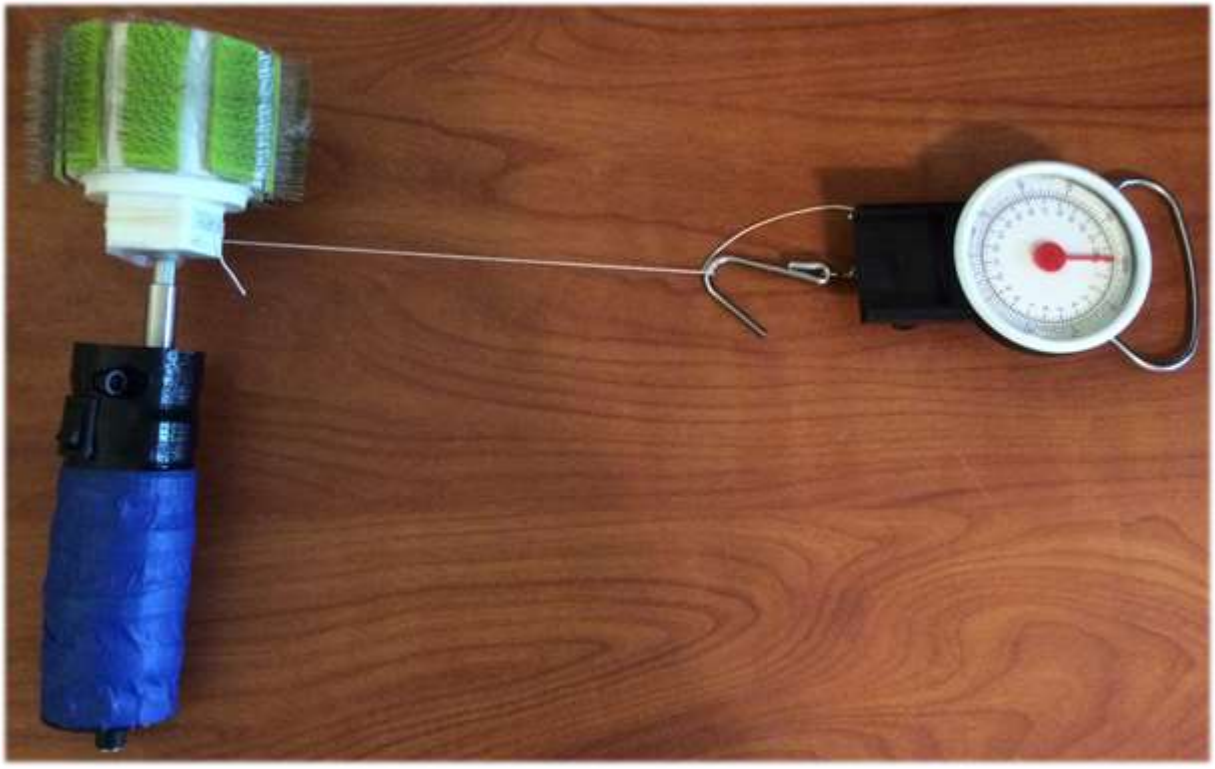


Figure 7: Testing the Motor Stall Force

To conduct the test, one end of the string was tied around the motor shaft adapter and the end was fastened to the spring scale that was held to a fixed location. The brush was then turned on and as the rope wrapped around the brush shaft on one end, it applied a tensile force on the spring scale on the other end, until the motor stalled. Once the motor stalled the force that the rope was applying to the spring scale was read off and taken as the maximum force at which the motor would stall. Table 8 is presented below showing the averaged results of different test iterations.

Table 8: Motor Stall Test Results

Radius Tested	***Tangential Stalling Force***	***Applied Stalling Torque***
0.6875 in.	4.68 lbs	3.2175 in-lbs
0.111 (motorshaft)	22 lbs	2.3627 in-lbs

Team 17 considered this force value to be the maximum because it was the minimum diameter around which the rope could wrap. Taking these results and applying them to an instance where it is a dog hair wrapping around the brush head, the force that the wrapping fur would need

to apply before the motor would be much less than the maximum. This is because the rated torque of the selected motor is approximately 2.7 in-lbs. The motor will stall is torque of equal or greater magnitude is applied to it. The torque applied to the motor is dependent upon the force and the distance at which that force is applied to the motor. The distance that wrapping fur exerts a force on the motor increases as the diameter of the brush head being used increases, meaning that the force required to stall the motor decreases as the brush head diameter increases. From the results of the test, the tangential applied force required for the motor to stall can be calculated and scaled for any brush head as long as the diameter is known.

4.2. Brush Head

4.2.1. Required Brushing Force

This test was done to determine the required brushing force that is typically needed when brushing using a manual brushing tool on animal fur. The materials needed to conduct this test were a manual dog brush, dog fur or some type of animal fur that is close, and a force measuring device. The FURminator was used as the manual brush, a cat was used for the fur, and a spring scale was again used. The spring scale was fastened to the handle of the FURminator and was pulled through the cat fur as shown in Figures 8 and 9. When the spring scale was being pulled on the brush was pulled through the fur, and the amount of force being exerted was taken as being less than one pound.

Figure 8: Required Manual Brushing Force Test

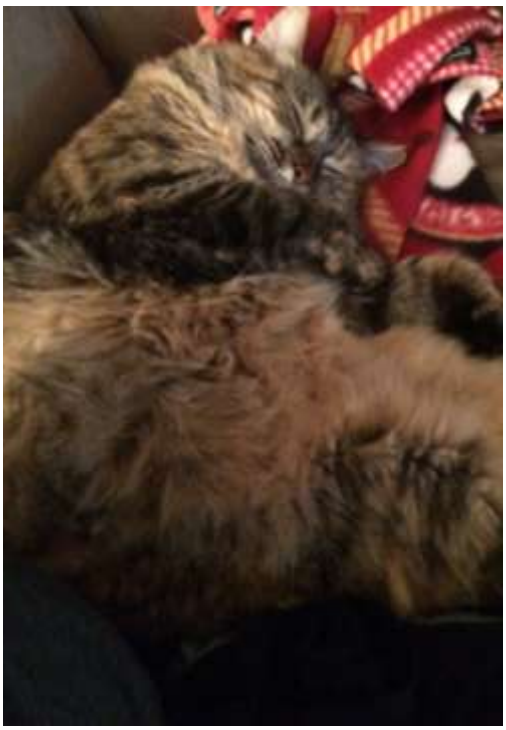


Figure 9: Cat Fur Tested On

4.2.2. Optimal Dimensions

The optimal dimensions for the brush head include the diameter of the brush head body and the length of the brush head. These dimensions needed to be optimized because they greatly affected the overall effectiveness of the brush. The diameter affected the ability of the brush head to go through the dog fur without the fur wrapping on the brush head body. To test for the optimal diameters, several brush heads, as shown in Figure 10, whose varying dimensions are shown in Table 9, were adapted to the grooming tool, and applied to various to the fur of the dog shown in Figure 11.

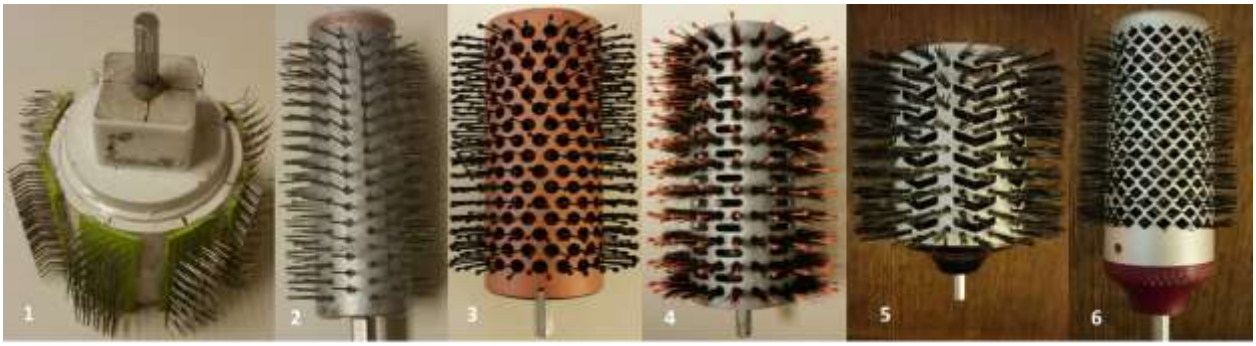


Figure 10: Various Brush Heads Tested

Table 9: Brush Head Dimensions

Brush Head	*Diameter (inches)*	*Length (inches)*
1	2.7	3.4
2	1.0	5.0
3	1.7	4.8
4	1.9	5.0
5	3.2	4.2
6	1.7	4.5

Figure 11: One of the dogs brush heads were tested on

Due to the number of brush head deigns that were being evaluated tested it was very difficult and costly to maintain the same constants with each iteration. Certain patterns began to develop from each test, and from these, Team 17 was able to determine which dimensions would work best regardless of the bristle design. From the tests, a relationship between fur length and brush head diameter was formulated as the longer the dog hair, the larger the brush head diameter needed to be. After testing the brush head it was evident that the optimal range for brush head

diameter was (1.75 in. ≤ Diameter ≤ 4 in). When concluding this optimal diameter range it was also noted that the larger the diameter the less force applied by the dog fur it would take to cause the motor to stall. A brush head with a diameter over four inches could possibly end the issue of wrapping completely, but it may also decrease the overall effectiveness of the brush. The optimal length was concluded to be 3 in. ≤ Length ≤ 6 in. The reason for the minimal length being three inches, is because a brush head that is smaller than three inches in length could increase the time spent using the brush, due to the smaller dog fur surface area it can cover at once. A smaller brush would only be useful for small dogs, but a longer brush head length could be used on a large dog as well as most small dogs. The maximum length of the brush head was established as 6 inches because Team 17 believed that 6 inches would provide ample dog fur surface area coverage, while maintaining ergonomics and user comfort. Having a brush head whose length exceeded that of the brush body could increase weight imbalances as well as the user's lack of overall control of the tool. With a longer brush head, forces and reaction moments are occurring farther away from the hand of the user, which can lead to larger torques acting on the user's hand causing fatigue and eventual pain.

4.3. Bristles

4.3.1. Tip Shape and Design

The best bristle tip design that would work for the rotary brush head was tested for in the same manner that brush head optimal dimensions were. Different brushes that had different bristle tip shapes were used on the test subject shown in Figure 12. There were three potential tip designs tested to see which ones were effective in going through tangles, and which ones had a tendency to lock on to fur and get stuck.

Figure 12: Test Subject for Bristles

The first design tip, Figure 13, was the bent tip design. This was tested on the different furs and the results showed that with a bent tip, the brush head could only be used in one direction. Angled brush tips were only safe on a rotating head if the bend on the bristles made the contact with the fur rather than the tips. This was because a rotating brush head with the pointed bristle ends making contact with the fur could possibly go too deep and dig into the dog's skin. Even if the bristle were to deflect, the pointed ends making an angled contact with fur, put the dog's safety in jeopardy. These bristles were tested on faux fur first and the fur wrapped up in it every time.

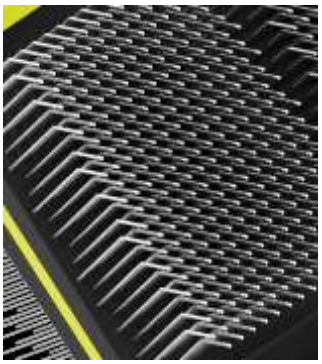


Figure 13: Bent Bristle Tip Design

The second bristle design was the balled end, Figure 14. The balled design was tested on all the furs, and its results showed that successful use was dependent upon the diameter of the brush head and the length of fur. The brush heads that were used to test ball design included brush heads with only balled tip bristles and those with a combination of balled tips and straight tips. The specific brush heads that were used were brush heads three and four from Figure 10. On the faux alpaca fur, the ball tips grabbed and locked into the fur, but on the tail fur of a real dog as shown in Figure 11 the balled tips did not wrap as much and effectively straightened the tail fur.

Figure 14: Balled Tip Bristles

The last bristle design that was tested was the straight bristles, shown in Figure 15 on brush heads two, five, and six. Although the brush heads varied in diameter the nature of the straight bristles on a brush head spinning in fur was evident. For smaller diameter brush heads like the brush head two, the straight bristles would only wrap up the hair. As the diameter of the brush head began to increase the straight bristles began to smooth out the tangled faux fur and real dog fur.

Figure 15: Straight Bristles

4.3.2. Materials

There were three possible materials from which the bristles could be made for the rotary brush, stainless steel, plastic, and hog hair. Team 17, tested the rotary brush using different heads with vary bristle material to determine which bristle material worked the best. Key characteristics that the material needed to have was the ability to deflect a certain amount when a force was applied to it from the fur.

The first bristle material to be tested and analyzed was stainless steel, found on brush one in Figure 10. The brush head containing the stainless steel bristles was a PVC pipe with pieces of a slicker brush, Figure 16, glued around it. The deflection displacement of the stainless steel was calculated using Equation 1, were blank is blank and. The deflection angle of a single stainless steel bristle was also calculated with Equation 2, where P is force in lbs, L is length in inches, E is the elastic modulus, ksi, and I is the moment of inertia.

Figure 16: Slicker Brush

$$x = -\frac{PL^3}{(3EI)} \quad (1)$$

$$\theta_d = -\frac{PL^2}{(2EI)} \quad (2)$$

The results of the calculations showed that the deflection displacement for a single stainless steel bristle was 0.183 inches, and the deflection angle was 15.6 degrees. The stainless steel bristles also happened to be the bristles with the bent tips that did not perform as desired in the previous tests. Video was taken of the stainless steel bristles being used on the faux fur, and when slowly played back it could be seen that the issue with the stainless steel was that there was no deflection. The stiff bristles kept locking into fur that was smoothed out, and it became evident that a material that had greater deflection was needed.

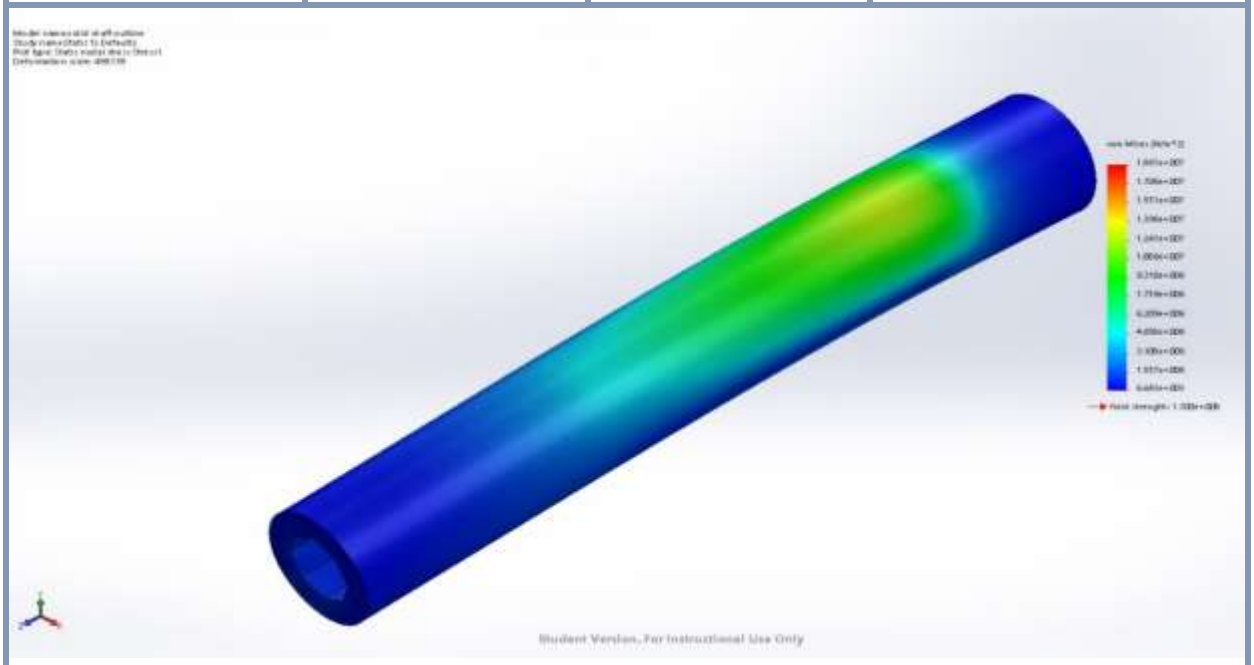
The other two bristle materials that were tested were the hog hair and the plastic bristle, and they are shown on brushes two-six in Figure 10. When testing the hog hair bristles and plastic bristles, Team 17 was evaluating the amount of deflection that occurred when the bristles were used on either of the furs. The team knew that results of the fur wrapping around the brush head body would not be solely due to the lack of deflection, but it was understood that if the diameter

of the brush was within the optimal range, then the lack of deflection could be the reason. There were two types of wrapping that could occur. The first type of wrapping was when the hair would wind up around the brush head. When this occurred it was due to the hair being too long and the brush head diameter being too small. The second type of wrapping was when the brush would lock into the hair and no longer work through, leaving the skin to begin the pull. This wrapping was more of snag, as it was due to the lack of deflection, and was what the team was looking for. To test the plastic bristles brush head four from Figure # was used. The plastic bristles deflected more than the stainless steel ones, and so the wrapping due to snagging was significantly reduced. To evaluate strictly hog hair bristles, brush five from Figure was used. The results from its use revealed that hog hair deflects the most and the only wrapping that occurred was due to the length of the dog hair and not the lack of deflections. When used on the dog in Figure 11, the dog showed no signs of stress or pain as even the contact of the bristles with the skin did not lead to any sort of brush burn.

4.4. Motor Shaft Adapter

FEA was conducted on the motor shaft adapter to determine how the shaft would handle the various loads that it would see. The motor adapter shaft was implemented into the design to attach to the motor shaft so that it would endure the various bending and torque loads during brushing that would otherwise cause the motor shaft to fail. From the FEA results of Von Mises Stress it is seen that the adapter shaft handles the stress substantially well. Though difficult to read, the yield stress of the shaft is approximately $\sigma_y = 1.7 * 10^8 \frac{N}{m^2}$, from Figure 4 it can be seen that the highest Von Mises stress that the shaft could possible see is only $\sigma_1 = 1.86 * 10^7 \frac{N}{m^2}$, and from Figure 17 it can be seen that the shaft never sees that stress level

Name	Type	Min	Max
Stress1	VON: von Mises Stress	6643.38 N/m^2 Node: 121	1.86124e+007 N/m^2 Node: 9832



solid shaft outline-Static 1-Stress-Stress1

Figure 17: Shaft Adapter FEA

4.5. Overall Tool

The testing done for the brush heads and the various bristle designs provided enough results that reflected the overall effectiveness as a dog grooming tool. Team 17 used the results to assess the tools abilities solely as an improved dog brush as well as its effectiveness as a de-matter.

4.5.1. Brushing Effectiveness

As a dog brush the rotary grooming tool works excellently well, providing an improved performance than that of a manual dog brush. The improved performance of Team 17's dog grooming tool, is not based upon the tools ability to brush better than a manual brush. The rotary brush head is considered and improvement if it is able to provide at the least the same results with a decrease in the effort and work required. Based upon that criteria when used by a professional

groomer, Figure 18, the brush was able to smooth and style the dog fur just as well as the manual brush would have with less arm and wrist movement.

Figure 18: Rotary Dog Brush Being Used by Groomer

4.5.2. De-Matting Effectiveness

The results from the multiple tests indicate that the rotary brush does not remove mats as effectively as it would need to be considered as de-matter. The brush was effective in removing light mats on the surface of the dog fur, as shown in Figure 19, but the brush would only get caught on mats that are deep and advanced close to the dog's skin.

Figure 19: Rotary Brush Removing Light Mats

4.6. Result Summary

Table 10 below is the results of the tests and calculations done for the grooming brush and their characteristics

Table 10: Test Result Summary

Test Conducted	Purpose	Results
Motor Stall Force	Calculate max applied tangential force where motor stalls	**22.5 lbs**
Required Brushing Force	Determine the approx. force used to pull manual brush through fur	**≤ 1 lbs**
Shaft Bending Moment	Calculate max applied bending force that shaft would encounter	**Static: 8.4 lbs** **Dynamic: 25.7 lbs**
Brush Head Dimensions	Determine optimal brush head diameter and length	**3 in. ≤ Length ≤ 6 in** **1.75 in. ≤ Length ≤ 4 in**
Bristle Deflection	Calculate how much each bristle would deflect when force applied	**Displacement = 0.183 in** **Angle = 15.6 deg**
Bristle Design	Determine how well stiffer metal bristles handled fur	**Bristles tend to grab and pull hair without release**
Brushing Effectiveness	Compare prototype and manual dog brush to determine the more effective	**Brush successfully smoothed and straightened dog fur**
De-Matting Effectiveness	Determine how effective the rotating brush head is at removing mats from fur	**Brush could not break up deep mats, but was successful at removing mats on fur surface**

5. Final Design

The final design was chosen after careful examination of the subsystem decision matrices as well as preliminary testing of the different choices. In order to confirm that the decision matrices were in fact leading to the best option for each system, testing was done before selecting a final design. This allowed the team to be certain that the best materials and designs were being chosen.

The final design chosen, seen in Figure 20 was based upon concept design one and followed the guidance of the decision matrices on most subsystem options, but not all.

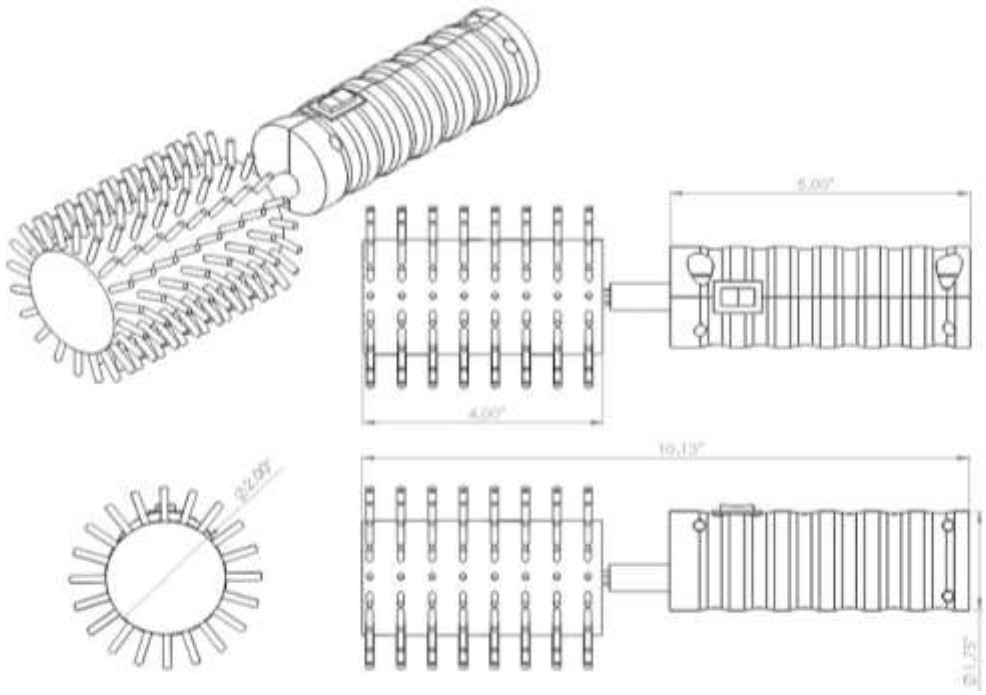


Figure 20: Final Design Prototype Drawing

Other key features of the final design include dual shaft bearings, a three position power switch, and an ergonomic 3d printed handle. The dual shaft bearings are used to support the lateral load placed on the motor shaft when the brush is being used. After analyzing the lateral load limits of the motor, the team realized there would be too much stress placed on the shaft without added support. The bearings take care of this problem without adding a large amount of excess weight.

5.1. Brush Handle

Another change the team made after testing was the ergonomic handle. The original concept handle was a simple round handle that offered no comfortable grip position. The final design handle has finger grooves that provide the user with a more ergonomic grip. The handle was fabricated through 3D printing using ABS plastic resin. By 3D printing the handle out of ABS, the overall weight of the brush is minimized as most of its handle weight comes from the electrical and mechanical components it houses.

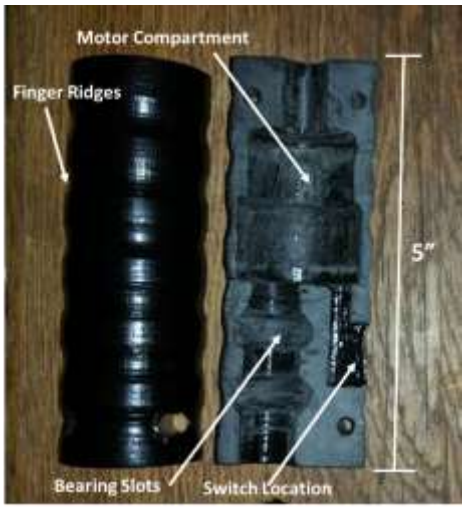


Figure 21: Brush Handle

5.2. Motor

The motor selected for the final design 12 volt DC, 60 rpm gear motor that is powered by plug in 120V-12V adapter. This design was favored over battery power because of its lighter weight and lower cost. Keeping the power supply and voltage adapter out of the handle helped keep weight to a minimum, thus reducing user fatigue. Although the motor seems somewhat small, the built in gearbox increases torque to a respectable 2.7 in-lbs. After testing the brush with different size brush heads and on different materials, it was determined that this amount power would be sufficient to pull the brush through thick fur but not so much as to pull the hair out.

Figure 22: 12 V DC Motor 60 RPM

5.3. Brush Head

After going through testing and evaluations of the six brush head designs selected in Figure, brush heads one and two were eliminated for the final brush head design. Brush head one, while fitting the diameter and length ranges, was eliminated due to the hazard that the mental, bent tip bristles pose for the user and the dog. Brush head two was eliminated despite having straight plastic bristles due to its tiny diameter. The small diameter of brush two caused serve wrapping and further fur entanglement when used on any other fur that was not thin and short. The remaining brush heads that were selected and their dimensions are shown below in Figure 23 and Table 11. The brush heads meet the optimal dimensions as well as contain the correct bristle designs and

materials. It is necessary to include various brush heads as a part of the rotary grooming tool's final design, because dog fur varies greatly and the goal is to have a tool that is useable for as wide a range of dog fur types as possible

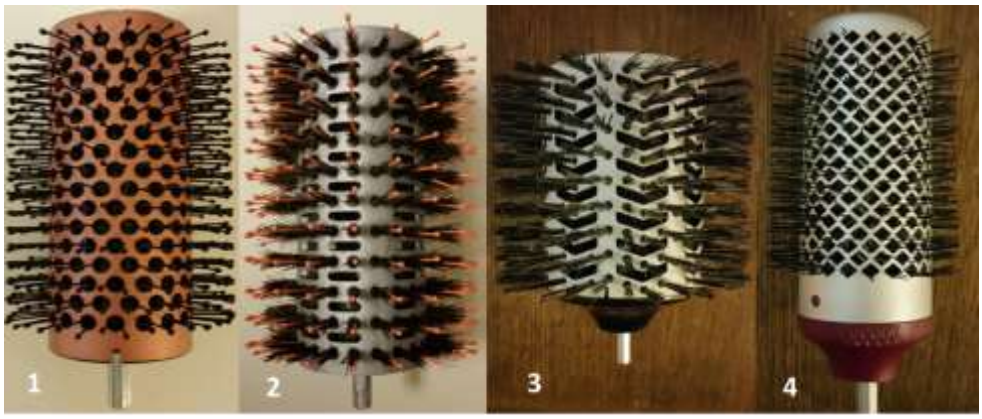


Figure 23: Final Brush Heads

Table 11: Final Brush Head Dimensions

Brush Head	*Diameter (inches)*	*Length (inches)*
1	1.7	4.8
2	1.9	5.0
3	3.2	4.2
4	1.7	4.5

5.4. Bristles

After extensive testing of the different bristle materials available, it was found that a metal bristle was not the best option for this application. Although very durable and a high performer on the decision matrix, metal bristles posed too much of a safety risk to be implemented on the final design. As a substitute for the metal, its runner up on the decision matrix, plastic, was chosen. It was a close second to metal on the decision matrix. Plastic's high scores in user and pet comfort were confirmed after testing was completed. Doing away with the sharp edges of the metal bristles and replacing them with plastic, makes the user feel more comfortable when using the brush because there is much less chance of injuring either the pet or themselves. The softer plastic material used in the final brush also allowed for more flex when brushing through thick fur. By bending more as fur gets thick, the plastic bristles tend to grab less and cause less discomfort to the pet. Another bristle material that was not considered before, and so was not evaluated in the

bristle design decision matrix in Table 7 are hog hair bristles. Brush heads that had hog hairs were much better in performance and safety than the plastic and metal bristles, as the hog hair bristles deflected more and had softer tips than any other straight tipped bristle. The bristle types selected can be seen above on the brush heads in Figure 23. Brush head one has plastic bristles with ball tips, brush head two has plastic bristles with ball tips and straight tipped hog hair, brush three just uses straight hog hair bristles, and brush four uses straight plastic bristles.

5.5. Reversible Switch

The three position power switch was an addition the team made after testing the prototype brush. Realizing that the brush head needed to be able to rotate in both directions for left and right handed users, as well as to provide the users with the ability to automatically unwind the brush, head should it get wrapped up in anything, the original on/off switch was changed to a three position toggle switch. This toggle switch allows the motor to rotate in both direction and adds no additional equipment or weight the brush.

6. Manufacturability

6.1. Fabrication

Prior to assembly, various parts of the brush assembly required fabrication. Parts were either fabricated in house, at the College of Engineering machine shop, or were outsourced to shops with access to 3d printers. The handle was designed to be 3d printed to reduce cost as well as manufacturing time. The handle was designed as a two-piece assembly to reduce assembly time as well. The motor shaft was the only other part that required much fabrication time. In order to reduce labor time as much as possible, a prefabricated power drill extension bit was modified to fit the application. Due to the complexity of machining the hex socket in the end of the bit, modifying a pre-fabricated bit was the cheaper and quicker method to take. In order to adapt the drill bit extension to the brush application, it was necessary to cut it down to the appropriate length as well as machine a hole on one end for the motor shaft to fit into.

Due to the complexity of manufacturing a brush head, it was decided to use prefabricated brush heads that are commonly available and adapt them to work with this application. Very little fabrication time was required by doing so. The only modifications required to make the brush heads attach to the motor shaft was to remove the old handle from the brush head and attach a

short piece of ¼" hexagonal stock which fits into the existing hole in the drill bit extension. This was done by drilling a ¼" hole and using a hexagonal broach, provided by the College of Engineering machine shop, and pressing in the hexagonal stock.

Other brush components, including the motor, switch, bearings, and power source, were all purchased prefabricated. Due to the complexity of these components, as well as their availability, it was found the quicker and more cost effective to purchase as many parts as possible versus custom fabricating them.

6.2. Assembly

Once fabrication of the components was completed, assembly of the components could begin. Because the brush was designed with ease of assembly in mind, assembly time and labor were kept to a minimum. The internal components of the brush handle required no assembly of their own so they were able to be dropped into their respective slot which was designed into the handle. The motor, shaft, bearings, and switch all had specific slots in the handle where they simply dropped in and were held solidly in place. Once fit of these internal components was checked, the motor switch and power source were wired together. This step was the most time consuming as the terminals on the motor and switch required the leads to be soldered on. After wiring was completed and the motor was checked for rotation, the two handle halves were joined together and held in place by three screws.

As stated earlier, the brush was designed with ease of assembly in mind. The cutouts for the internal components of the brush allowed to be quickly dropped in place and required no extra securing. The number of components was also kept to an absolute minimum. This was primarily driven by the weight constraint placed on the project, but also cost concerns when fabricating and assembling. By taking these extra steps when designing, it allowed the initial prototype to be completely assembled in roughly one hour's time, the bulk of this time devoted to wiring. With more practice and an assembly line method, this time could be reduced much further. Mass production of these assemblies would then be very possible.

Table 12: Final Design Components List

ITEM NO.	DESCRIPTION	QUANTITY
1	60 RPM DC Motor	1
2	Motor Shaft Adapter	1
3	Motor Shaft Bearing	2
4	½ Grooved Handle	1
5	½ Grooved Handle Counterbored	1
6	Reversible Power Switch	1
7	¼-20 Cap Screw	3
8	Brush Head	1

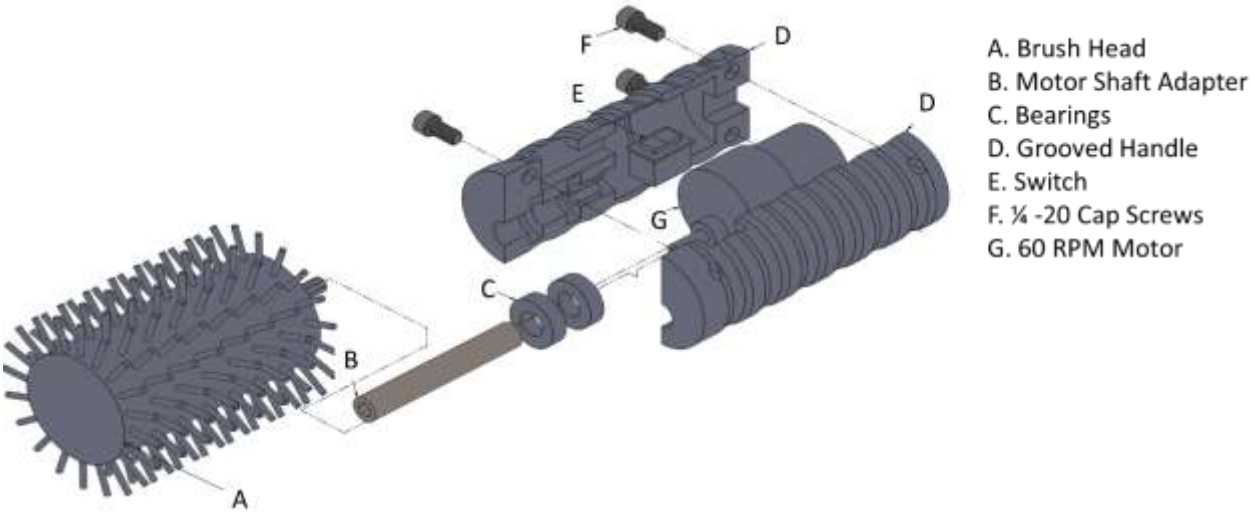


Figure 24: Final Prototype Design Exploded View

7. Reliability

7.1. Failure Mode and Effects Analysis

The FMEA was conducted on the overall dog brush, in order to initiate a step-by-step process to identify any area of possible failure for the brush. The area of design that was analyzed was possibilities of failure in the brushes ability to detangle fur. The FMEA focuses on the two potential areas of failure where the brush is not powerful enough to go through the dog fur and then the instance where the bristles are too soft and they deflect over the fur than go through it. Figure 5 below shows the step by step process that was conducted and the possible contingencies to counteract the failure.

Table 13: Prototype FEMA

Function	Potential Failure Mode	Potential Effects of Failure	Severity (1-10)	Potential Causes of Failure	Occurrence (1-10)	Process Controls	Detection (1-10)	RPN	CRIT	Action Plan
Detangle Fur	Motor not powerful enough to brush through fur	Motor overheats from excessive loading, Brush becomes stuck in hair, Product does not meet spec	10	Incorrect motor size	7	Select motor with minimum torque needed	4	280	70	Test force needed to pull through matt
				Bad motor installed	1	Test motor before installing	1	10	10	Have multiple motors on hand
				Motor/ shaft binding	5	Check tolerances and check for debris	2	100	50	Design to keep debris out, Test life cycle of product, determine test plan for aplied forces
	Bristles to soft and don't break up matt	Brush doesn't meet itnitial goals	9	Incorrect size wire installed	6	Ensure correct tolerances for manufacturing	2	108	54	Measure bristles on existing brushes
				Length of Bristles	6	Ensure correct tolerances for manufacturing	3	162	54	Measure length of bristles on current brushes

8. Operations Manual

8.1. Pre-Operation

Prior to operation of the device, ensure that all components are properly assembled and are in proper functioning order. Check that all screws and bolts are securely fastened and all stationary components are not able to move. Likewise, make sure that all components intended to move are in fact moving in the way they should be. Check for any cracks, breaks, or flaws in the device that

could result in catastrophic failure once the device is powered on. Inspect the power supply and cable to ensure that it is in proper working order and there is no damage to its components. Check that the brush head shaft is firmly seated in the motor shaft. Once all components have been inspected, it is then possible to power on the device and begin operation.

8.2. Operation

1. Read and follow all pre-operation instruction before powering on the device.
2. Confirm that power switch is in the off position and power supply is unplugged.
3. Locate desired brush head attachment based upon dog hair type and length.
4. Attach the brush head to handle assembly by firmly inserting the brush head shaft into motor shaft until it is secure.
5. Locate power supply and check cable for any possible damage.
6. Plug male end of power supply cable into the female connector on bottom of brush assembly.
7. Plug power supply into a 120 volt household outlet until secure.
8. Turn power switch to on position and confirm that brush head turns freely and does not bind.
9. Slowly groom dog taking care to not let hair tangle or wrap around brush.

8.3. Maintenance

Some regular maintenance will keep the tool lasting for a long time. Routine things an operator should do is clean the tool after each use to prohibit the spread of diseases if using the tool on multiple animals. If using the tool on one animal each time, cleaning the tool will still be a good idea after each use. To clean the handle, dip it into bleach water and rinse thoroughly. To clean the brush head, pull off any hair on the head and then dip into bleach water and rinse with clean water. All internal components should remain dry during this process due to proper sealing. The tool must be unplugged and remain off during the cleaning. No other parts need to be cleaned.

If water leaks through the handle then unscrew the two pieces that make up the handle and dry each component. Reattach the handle after the internal parts are dry and you may test the tool to see if it still works. If not, please call the customer service phone number. If the tool works then try and fix the leak issue with a troubleshooting solution.

The brush heads are detachable so that different sizes may be used when necessary. If the bristles begin to fall off due to being worn down then you will need to replace the entire brush head. If the shaft on the brush head becomes loose then you will need to replace the whole brush head. The brush heads are designed to last for a few years depending on the daily usage. If troubleshooting does not work when the tool is not turning on then you will need to order a new handle.

8.4. Troubleshooting

Potential problems that may arise when operating this tool are displayed in Table 14. These problems may arise due to overuse or misuse. Overuse may occur when the lifetime of individual components are met such as the motor and adapter. Other components like the shaft or handle can deteriorate over time from wear and tear. When not operating the tool correctly the components might fail sooner than expected. If these problems arise, trying one or more of the solutions provided in the table should resolve the issue. If after trying all solutions, please call the company's customer service phone number to resolve any issue.

Table 14: Troubleshooting Solutions

Problem	Reason	Solution
Brush head is not rotating	Brush head is wrapped up into hair	Reverse directions to unwrap brush head
	Brush head shaft is loose and spinning inside brush	Replace brush head
Electric brush is not powering on	Brush tool power adapter is not properly inserted into wall outlet	Check power outlet, ensure adapter is correctly plugged in
	Switch is malfunctioning	Return to manufacturer to have switch replaced
	Electrical short/ Wire fraying/ Adapter malfunctioning	Replace adapter
Brush Handle Fracture	Manufacturing Error	Replace handle immediately due to safety concerns with housed electrical internal components
	User Error	
Water or fluid leaks inside brush housing	Crack / Fracture in brush handle	See Fracture Problem
	Handle is not securely fastened together	Tighten screws
		Check for holes and fill with rubber or sealant

Bristles falling out of brush head	Wear and tear	No replacing of bristles can be done. If several bristles come off then a new brush head is required
	User error	
	Manufacturing error	

9. Environment, Safety and Ethics

When used properly the tool is safe for the operator, animal, and the environment. A manual will be made when the final product is constructed that provides directions on how to operate the tool, any safety precautions, and cleaning directions. All the materials used will be capable of normal disposal in local trash. Some of the parts including the plastic can be recycle if desired. The tool is leaning away from battery operated but if that was an option then a small battery pack may be installed. If this is the case then by going to the website Call2Recycle.org you can find a nearby drop-off site to dispose of the battery. If one does not want to travel to this site due to it being too far then they can try calling 800-CLEAN-UP and they will list recycling resources. All else fails contact the local sanitation and they will help the owner.

Other dangers or risks to the environment is the possibility of the tool being used as a weapon. The tool will be at most a pound on weight so this does not pose as a probable issue but there is no way of predicting what a person will do. This tool in no way should be used other than grooming an animal. Any type of other use may cause injury or harm to the victim. Final safety concern is cleaning of the tool. Contact of any plastic or rubber to the animal skin may irritate the area. Avoid making contact with the animal's skin. Only the bristles will be touching the animal and it will touch just the fur. If a skin irritation produces, contact your local vet clinic for assistance. Also cleaning the tool regularly is needed to make it last longer and required if using on different animals to prevent transfer of disease or germs. To clean the device, simply dip it into a cleaning solution and then rinse with water heavily. Any leftover residue from the cleaning solution could cause harm to the operator and animal.

10. Project Management

10.1. Project Schedule

The schedule for this project is shown in the gantt charts below in Figures 25 and 26. The project was able to follow the schedule fairly well, with only a few instances where the deadlines had to be extended. Creating the schedule was a learning situation, as Team 17 was initially unaware as to how long certain steps and tasks would actually take. Phase one from Figure 25 was

where the research and preliminary design and concept forming was done. Phase two in Figure 26 was the testing and redesign and assembly part of the project.

One area in the scheduling that Team 17 fell short in was in the research of alternative designs at the end of phase one. The team decided that it would be wiser to keep the focus on the current successful design at that time to make sure that it was properly developed and ready for testing in phase two

Task Name	Dura	Start	Finish
Initial Conceptual Designs	**23 days**	**Mon 9/21/15**	**Wed 10/21/15**
Risk Assessment	8 days	Mon 9/21/15	Wed 9/30/15
Design Decision Matrix	20 days	Mon 9/21/15	Fri 10/16/15
Voice of the Customer Report	3 days	Mon 10/19/15	Wed 10/21/15
Design Research	**55 days**	**Mon 9/21/15**	**Fri 12/4/15**
Research Similar Designs	35 days	Mon 10/19/15	Fri 12/4/15
Research Essential Design Components	20 days	Mon 9/21/15	Fri 10/16/15
Research Fabrication Options	15 days	Mon 9/28/15	Fri 10/16/15
Research Retail Options	15 days	Mon 9/28/15	Fri 10/16/15
Research Material Possibilities	15 days	Mon 9/28/15	Fri 10/16/15
Research Assembly Options	10 days	Mon 10/5/15	Fri 10/16/15
Design Selection	**23 days**	**Mon 10/19/15**	**Wed 11/18/15**
Select Material	21 days	Mon 10/19/15	Mon 11/16/15
Select Fabrication Method	21 days	Mon 10/19/15	Mon 11/16/15
Select Motor	21 days	Mon 10/19/15	Mon 11/16/15
Select Brush Head Design	21 days	Mon 10/19/15	Mon 11/16/15
Select Enclosing Method	21 days	Mon 10/19/15	Mon 11/16/15
Select Electrical Components	21 days	Mon 10/19/15	Mon 11/16/15
Select Retail Option	16 days	Mon 10/26/15	Mon 11/16/15
Select Assembly Method	6 days	Mon 11/9/15	Mon 11/16/15
FMEA	6 days	Wed 11/11/15	Wed 11/18/15
Design Approval	**0 days**	**Wed 11/18/15**	**Wed 11/18/15**
Order Parts	**13 days**	**Thu 11/12/15**	**Mon 11/30/15**
Order Motor	13 days	Thu 11/12/15	Mon 11/30/15
Order Bristle Materials	13 days	Thu 11/12/15	Mon 11/30/15
Order Power Source	13 days	Thu 11/12/15	Mon 11/30/15
Order Fusion Method Parts	13 days	Thu 11/12/15	Mon 11/30/15
Test Planning	**17 days**	**Thu 11/12/15**	**Fri 12/4/15**
Fabrication	**8 days**	**Thu 11/19/15**	**Mon 11/30/15**
Build Prototype	**4 days**	**Tue 12/1/15**	**Fri 12/4/15**
Research Alternative Designs	**61 days**	**Mon 12/7/15**	**Mon 2/29/16**

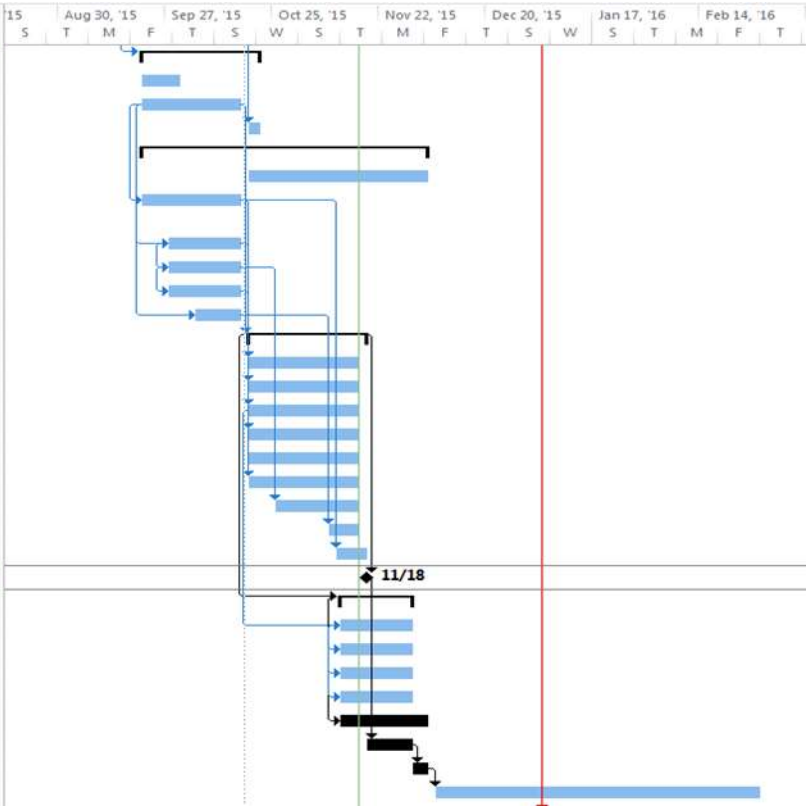
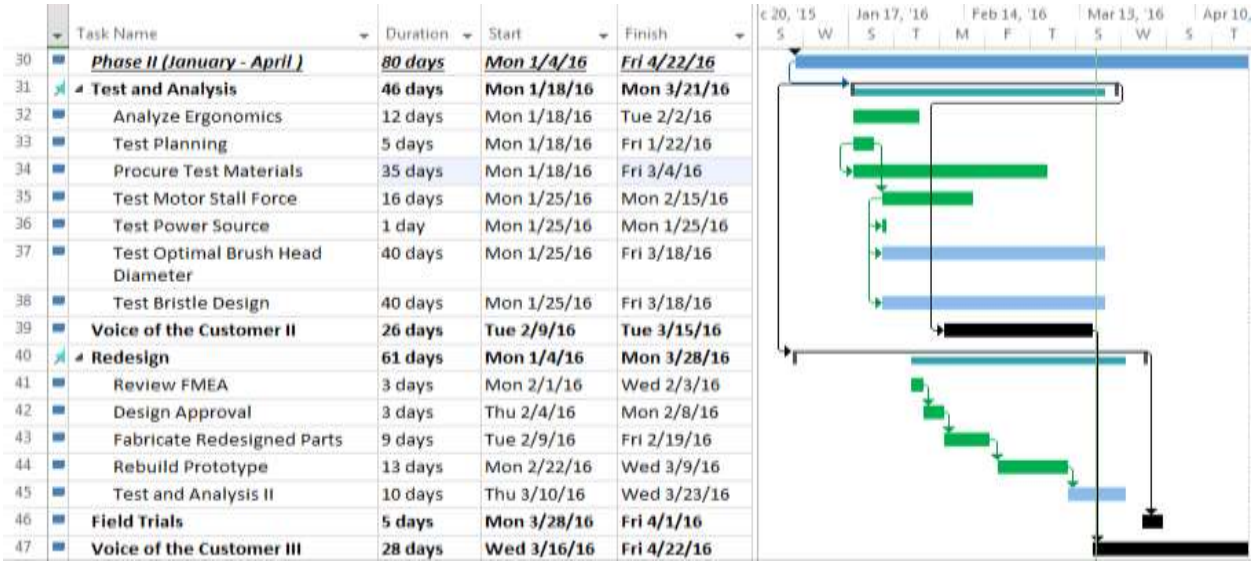


Figure 25: Fall 2015 Gantt Chart Schedule



	Task Name	Duration	Start	Finish
30	***Phase II (January - April)***	***80 days***	***Mon 1/4/16***	***Fri 4/22/16***
31	**Test and Analysis**	**46 days**	**Mon 1/18/16**	**Mon 3/21/16**
32	Analyze Ergonomics	12 days	Mon 1/18/16	Tue 2/2/16
33	Test Planning	5 days	Mon 1/18/16	Fri 1/22/16
34	Procure Test Materials	35 days	Mon 1/18/16	Fri 3/4/16
35	Test Motor Stall Force	16 days	Mon 1/25/16	Mon 2/15/16
36	Test Power Source	1 day	Mon 1/25/16	Mon 1/25/16
37	Test Optimal Brush Head Diameter	40 days	Mon 1/25/16	Fri 3/18/16
38	Test Bristle Design	40 days	Mon 1/25/16	Fri 3/18/16
39	**Voice of the Customer II**	**26 days**	**Tue 2/9/16**	**Tue 3/15/16**
40	**Redesign**	**61 days**	**Mon 1/4/16**	**Mon 3/28/16**
41	Review FMEA	3 days	Mon 2/1/16	Wed 2/3/16
42	Design Approval	3 days	Thu 2/4/16	Mon 2/8/16
43	Fabricate Redesigned Parts	9 days	Tue 2/9/16	Fri 2/19/16
44	Rebuild Prototype	13 days	Mon 2/22/16	Wed 3/9/16
45	Test and Analysis II	10 days	Thu 3/10/16	Wed 3/23/16
46	**Field Trials**	**5 days**	**Mon 3/28/16**	**Fri 4/1/16**
47	**Voice of the Customer III**	**28 days**	**Wed 3/16/16**	**Fri 4/22/16**

Figure 26: Spring 2016 Gantt Chart Schedule

10.2. Resources

The availability of resourceful facilities allowed the design and development of the improved dog grooming tool possible. Team 17 was able to use local 3D printing as the means to fabricating the lightweight ergonomic handle through the local businesses Function 3D, and Danfoss Turbocor. The team also had daily access to the FAMU-FSU College of Engineering Machine Shop and the subsequent tools that were necessary for assembling the brush. Team 17 also had access to a professional dog grooming environment at the facilities of Paws ‘n’ Claws, where they were graciously allowed to perform tests, as well as shadow professional groomers, and learn the dog grooming process.

10.3. Procurement

10.3.1. Bill of Materials for Project

The complete bill of materials for this project, found in Table 15, covers all the different materials and items purchased to implement into the design, test the design, or to evaluate the optimal design component characteristic. The table includes items that were a part of the final design prototype as well as the parts that were initially selected but removed as better ideas and components were discovered

Table 15: Project Complete Bill of Materials

ITEM NO.	DESCRIPTION	QUANTITY
1	60 RPM DC Motor	2
2	Motor Shaft Adapter	2
3	Motor Shaft Bearing	4
4	Brush Handle	4
6	Reversible Power Switch	1
7	Flip Switch	1
8	¼-20 Cap Screw	6
9	Brush Head	10
10	Fox fur	1
11	Faux Alpaca Fur	1
12	Spring Scale	1

10.3.2. Financial Breakdown

At the beginning of this design project the sponsors defined the budgetary constraints and that was that $500.00 would be supplied to the team to research test and build five prototypes that would be market ready. Team 17 was able to use the funds to design, test, and build one full prototype and begin the construction of the second. Based on the financial breakdown for this project as shown in Figure ##, it is clear that Team was not able to stay within the initial budgetary constraints. As this was made known to the sponsor, the constraints were flexed allowing the amount of money provided for the construction of the prototypes to be expanded. One major reason why the project went over the budget constraints was due to the purchasing of the testing material. When testing the various brush heads and bristle design, the team did not necessarily want to jump right into testing on live dogs. It was unknown how any preliminary prototypes like the stainless steel bristles would respond, and so not wanting to injure a dog Team 17 exhausted some of the funds simply trying to find a fur that would closely relate to a dog's. Figure 27 only shows the funds spent overall and how much remains. This graphic can give the misled perception that it costs over $200 to make one prototype. To debunk that idea, Table ## is provided below which illustrates the actual cost that it takes to construct and fabricate one rotary brush. The total of $90 means that five prototypes could be made for less than $500.

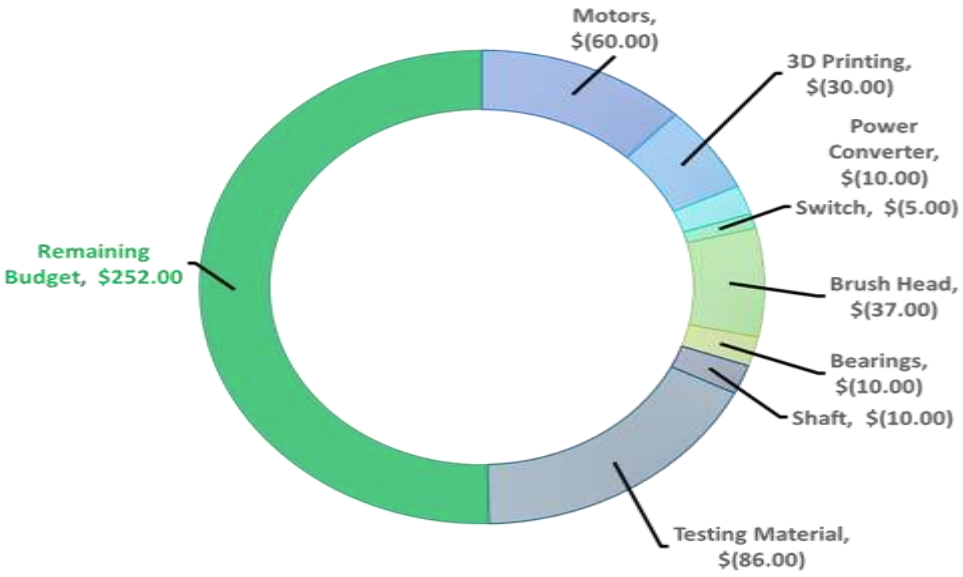


Figure 27: Financial Breakdown Chart

Table 16: Cost for One Prototype

BRUSH COMPONENT	COST
MOTOR	$16
SHAFT	$10
BEARINGS (2)	$10
BRUSH HEAD	$9
HANDLE	$30
POWER CONVERTER	$10
SWITCH	$5
TOTAL	$90

10.4. Communication

10.4.1. Sponsors

Team 17 initially began to communicate with it sponsors through email and conference phone calls through the initial few weeks of the project. There were two sponsors for this project, Bill Bilbow who lives in Tallahassee, FL, and works locally at Danfoss Turbocor, and Todd Hopwood, who lives and works in Houston, TX, and owns his own engineering company "*Engineering To Go*". The team has maintained consistent communication with Bill Bilbow throughout the fall 2015 semester and the spring 2016 semester. During fall 2015, the team met with Bill Bilbow on Wednesday's at 4 pm, and then during the spring of 2016, the team with him on Monday's at 4 pm. During these weekly meetings the team would update Mr. Bilbow, on the

design progress that had been made since the last meeting, issues and setbacks that had come about, questions, on future directions, and upcoming deadlines for the class. The distance between the team and Todd Hopwood caused some issues in communication. Mr. Hopwood, would rarely attend the weekly meetings, coming about once every 3 months. His rare appearances slowed meeting agendas and procedures because most of the meeting was spent filling him in on months of occurrences and it would prevent the team from discussing new relevant info. As the spring semester progressed communication with Mr. Hopwood dried, but Mr. Bilbow and the team continued consistent communication and were able to continue progressing in the project.

10.4.2. Faculty Advisor

Team 17's faculty advisor was Dr. Simone Hruda, assistant professor at the FAMU-FSU College of Engineering. The team at Dr. Hruda would meet once a week to discuss project progress, and discuss any road blocks that were preventing the team's advancement with the project. The meetings were time efficient as they only lasted 30 minutes and only two team members were required to attend each meeting. This arrangement worked very well for the instances where team members were unable to attend the meetings. The only issue that ever arose in communications with Dr. Hruda for Team 17, was when her class advising time would overlap into the teams meeting time. When such a situation would occur, it was resolved through rescheduling or just a quick briefing by the team members, updating Dr. Hruda of the most recent occurrences. Disruptions during faculty advisor meeting times was on minor issue because team members, would simple catch Dr. Hruda on other days throughout the week, debrief and then relay the meeting info to the team members. One major communication issue that did occur with Dr. Hruda, was that the team would not collaborate with her to establish a presentation time that she could attend. This led to several presentations being held without her in attendance. This issue was remedied by the team find out her schedule and picking times to present that fit with her availability

10.4.3. Course Advisor

Communication with the course advisor was maintained through staff meetings as well as emails, and class lectures. Class lectures were instructional based where the course advisor Dr. Nikhil Gupta, would inform us of the course schedule, deliverable dates, and the expectations on reports and presentations. Any timely changes or announcements were provided between the team and Dr. Gupta via email, and posted announcements of the college academic portal. Staff meetings

with Dr. Gupta would occur the weeks following team presentations, where the team would provide an update on the current status of the project, what had been accomplished and any issues that had arisen. With the staff meetings the team was able to also receive advice as to what it needed to do in order to stay on schedule and meet the project deadlines.

10.4.4. Team Members

As a team, communication among the members was conducted on Facebook using the team's group messaging. The group page on Facebook was how the Team 17 informed each other of schedule updates, weekly plans, deadlines, conducted file sharing, reminded each other of meeting times and locations, as well as coordinated the splitting up of different tasks. In the case of the immediate need to communicate with each other Team 17 would occasionally call each other and text each other. There were not many issues with communication throughout the project among the team members. When the weekends arrived certain members would be unavailable which at times caused an inconvenience for members that were requesting information or documents. There were few occasions where members would not respond to messages, not show up to advisor meetings, or not attend field trips without any explanation of the absence beforehand. Such situations were confronted and dealt with as a team. At almost all team functions the majority of the team showed up and so the absence of one team member did not impact the overall progress of the project, although absences left team members in the dark as to what decisions had been made

11. Conclusion

11.1. Project Summary

Venturing into an entrepreneurial project was initially very challenging for Team 17. The project called for the development of a product from the ground up, for which the vision of the sponsors had to be quickly adopted. This project was a change of pace and differed greatly from other engineering design projects in that the customer was not the sponsor but rather the people who would be using the tool, a people that was unknown to Team 17. The success of this project was with the consumer and so the very first actions done was to go out and talk to people in the dog owning and grooming market, the team had to get to know the consumer understand their needs, evaluate the status of the market, whether this product being designed had any relevance, and then the technical aspect of the design and engineering could be explored.

The project was broken up into two phases. Phase one was conducted in the first semester, and it included a lot of research, and one on one interviews. Team 17 had to learn the grooming process and what the issues that the groomers and dog caretakers face when grooming their dogs. Phase one also included the development of concepts that would address and potentially solve the issues voiced by the consumers. From the concept generation, the team entered into a proof of concept phase where their sole objective was to see if a rotary mechanism would even work, tools like drills and Dremels were used to prevent the unnecessary wasting of funds and resources in an idea that would not even work. Once the concept was proved, the team began building a prototype based upon their concepts and design selection process. Phase one ended with the fabrication and assembly of a prototype which would then be tested in phase two.

Phase two was all about testing and redesign based on the results. Tests were conducted on all design components, most extensively on the brush head and bristles. As the team gathered the results from the test, the prototype design was adjusted and new iterations with new components and passing old components were created. Once a final prototype was reached with that passed all the tests, the prototype was taken back to potential customers, predominantly dog groomers. The team used the knowledge and insight from the consumer feedback, to make minor adjustments to the design and begin planning for the next steps in the design process.

Overall from the research, market analysis, and product development Team 17 concludes that they have a viable product that could very much make an impact with the way that humans car for their dogs. The initial desire was to make a tool that improved the process of removing mats from dog furs for the dog and caretaker. The rotary brush that was developed does not solve the issue of matting from the initial angle that the solution was approached, and that was by mat removal. From the voice of the customer, it was revealed that simply brushing a dog for many is a difficult task and unpleasant for the dog and owner, even when it is just daily brushing. Mats develop from the lack of brushing and constant care. If the dog is regularly brushed, the chances of mats developing decreases. With this understanding the rotary brush tackles the issue of matting from the approach of preventative methods. Constantly brushing a dog manually is tiring and strenuous especially for aging adults. The rotary dog brush is a successful design in that it takes the pain out of the brushing process, encouraging users to their dogs brush daily, resulting in a reduction in mat development.

11.2. Future Recommendations

Future work that should be considered for the further development of this project is to continue to research and discover a method to remove mats. The rotary brush works to prevent mats, but there is still a wide open market for a device that can improve the process of mat removal from dogs, either electronically or through automation. From interviews and conversations with professional groomers it is strongly believed that the best way is to use blades to break the mats up and bring them to the surface of the fur.

It is also strongly recommended that those that carry on this project stay in contact with Lori Williams, excellent experienced dog groomer at Paws and Claws, (3819 Bradfordville Rd, Tallahassee, FL 32309 - (850) 906-0444). She is very knowledgeable in the grooming process, dog behavior, and the functioning of a wide range of grooming tools. A lot of the success that Team 17 has had with this project is due to her help.

12. References

[1] J. P. J. C. D. P. Roy Mason, "Fall 2015 Final Report," EMl4550C Senior Design I, Tallahassee, 2015.

[2] J. P. J. C. D. P. Roy Mason, "Improved Dog Grooming Tool Operation Manual," EML 4552C Senior Design II, Tallahassee, 2016.

[3] J. P. J. C. D. P. Roy Mason, "Improved Dog Grooming Tool Manufacturability, Reliability, Economics," EML 4552C Senior Design II, Tallahassee, 2016.

[4] J. P. J. C. D. P. Roy Mason, "Improved Dog Grooming Tool Phase One Customer Discovery Summary," EML 4550C Senior Design I, Tallahassee, 2015.

[5] J. P. J. C. D. P. Roy Mason, "Improved Dog Grooming Tool Spring Update Presentation I," EML 4552C Senior Design II, Tallahassee, 2016.

[6] J. P. J. C. D. P. Roy Mason, "Improved Dog Grooming Tool Spring Presentation II," EML 4552C Senior Design II, Tallahassee, 2016.