Design Review #3:

Redesigning the Gutter Viper for Mass Production

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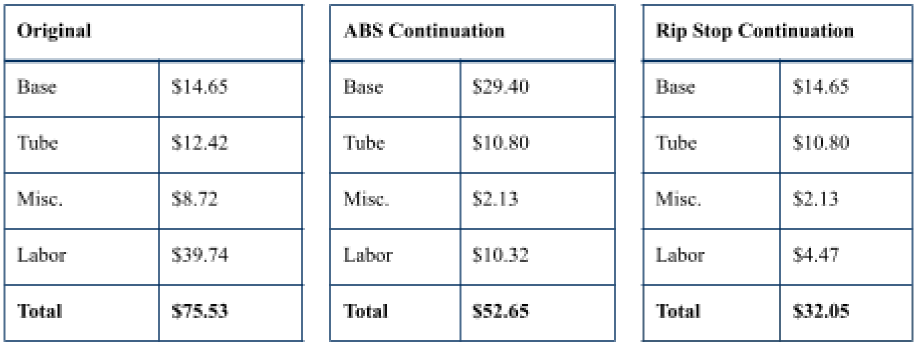
EXECUTIVE SUMMARY

The Gutter Viper is a tool compatible with most leaf blowers and painter poles that provides the ability for homeowners to clean gutters from the ground. While the current design's complexity in number of components and associated assembly process make the product expensive for customers, we have designed a new Gutter Viper that has reduced production costs by over 50%. This report will highlight the entire design making process for how we redesigned the Gutter Viper for mass production. In our design making process, we came up with two ideal solutions by first fully exploring the problem, then identifying and consulting with stakeholders, such as the original inventor and our sponsor professor Ashton-Miller. We then defined our three most important requirements and engineering specifications, as listed in Figure 1 below.

Figure 1. The top 3 most important requirements and specifications for the Gutter Viper

Requirement	Specification	Benchmarking	How to Test
Cleans Gutters	Cleans as well as the original Gutter Viper	Cleans all dry leaves	- Exit air speed - Force
Operate from the Ground	Can extend from leaf blower at least 20 feet	Includes 20 ft air tube	- Measure reach length
Low Cost	Unit Cost + Labor Cost < $25	- Unit Cost is $21.05 - Labor Cost is $40	- Get manufacturing quotes

We then performed various engineering analyses to narrow down our design selection for different components of the Gutter Viper. Specifically, we performed CFD analysis to investigate the most optimal tool inlet to outlet geometry for consistent mass flux of airflow. Additionally, we performed a ball float test to verify if selected concepts could maintain or further improve current product performance. We also practiced the assembly process for each selected design to roughly estimate the associated cost with labor times to assemble the product. From here, we have modeled our designs in CAD and worked with manufacturers, such as protolabs to get quotes. After meeting with Dr.Cooper, an industry professional in manufacturing solutions, we have decided to maintain the use of injection molding as the primary tool manufacturing method for its efficiency and low cost. In addition to the tooling and material part costs, we then used the labor costs and additional component costs to estimate the total cost for each design, as outlined below in Table 1.



Original	
Base	$14.65
Tube	$12.42
Misc.	$8.72
Labor	$39.74
Total	**$75.53**

ABS Continuation	
Base	$29.40
Tube	$10.80
Misc.	$2.13
Labor	$10.32
Total	**$52.65**

Rip Stop Continuation	
Base	$14.65
Tube	$10.80
Misc.	$2.13
Labor	$4.47
Total	**$32.05**

This final report serves as the final documentation for our sponsor professor Ashton-Miller to review our analysis and recommendations for further action in pursuing the re-designed Gutter Viper for mass manufacturing.

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SECTION 1: Project Introduction, Background, and Information Sources

When Professor Ashton-Miller saw his legally blind, elderly neighbor climbing a ladder to clean his gutters, he knew that there had to be a better way [4]. Every year, 120+ people die and 22,000+ people are injured from falling off ladders [7]. Therefore, Professor Ashton-Miller partnered with Dr. Terrell to create a device that attaches to a leaf blower and painter stick and allows a person to clean their gutters from the ground. Thus, the Gutter Viper was born [4].

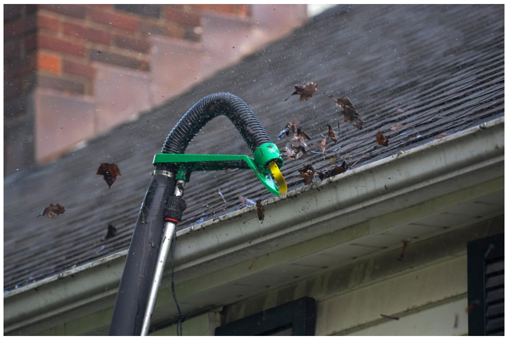


Image 1.1 The Gutter Viper cleaning a gutter [2].

The current Gutter Viper consists of 5 main components: the sled, nozzle, curved hose, tongue, and air tube as seen on the next page in Figure 1.1.

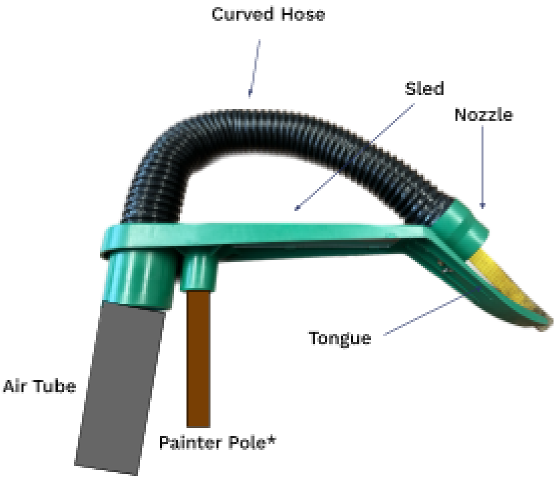


Figure 1.1 Main components of the Gutter Viper: curved hose, sled, nozzle, and tongue. The air tube that connects the Gutter Viper to the lead blower and the painter pole is what the customer uses to hold the Gutter Viper in the air. The painter pole is bought separately.

The sled and nozzle are injection molded with ABS while the curved hose and tongue are made out of stock material. The device also contains a mirror underneath the sled so that the user can see the inside of the gutter from the ground. This design is protected under patent US-9347223-B1 that claims a gutter cleaning device with a scoop and "leaf agitator" as seen in Figure 1.2 below [5]. Figure 1.3 also shows how the device is used in conjunction with a household leaf blower.

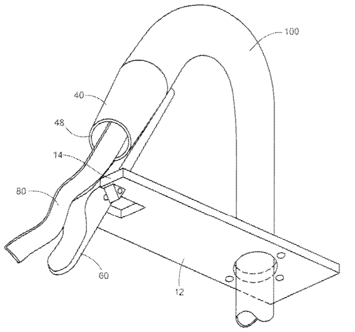


Figure 1.2 Official figure of the Gutter Viper patent showing the scoop and leaf agitator [5].

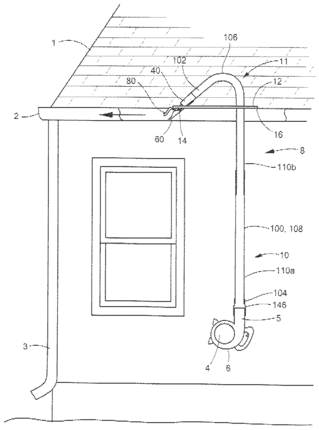


FIG. 1

Figure 1.3 Official figure of the Gutter Viper patent showing how the device is used with an attachment to a leaf blower [5].

The total production cost of the Gutter Viper is $16.99 with an additional assembly cost of $32.00 [3]. The air tube costs $11.95 to produce. With the inclusion of shipping, the Gutter Viper costs a total of $61.05 and retails for $115 [3]. While the Gutter Viper cleans the gutters exceptionally well, it is not the only other device on the market.

The Sun Joe Gutter Cleaning Blower Attachment is a device that can be purchased for $24.99 that attaches to the Sun Joe SBJ601E + SBJ603E + SBJ605E + iONBV blower models [15]. An image of this device is seen on the next page. The drawbacks with this device are that it only extends 15 feet and the user must already own one of the Sun Joe devices; it is not compatible with any leaf blower.

Image 1.2 The Sun Joe Gutter Cleaning Blower Attachment [14].

Additionally, the customers can also prevent leaves from getting in their gutters in the first place with gutter guards. Gutter guards are steel micro mesh panels that cover gutters, but still allow rainwater to flow through as seen in Image 1.3. While it may prevent large debris from entering, it does still allow small debris such as dirt and pine needles to slip through. Gutter guards can cost anywhere from $500 to $2000 including installation [15]. If a homeowner decides to install it themselves, they still need to climb a ladder.

Image 1.3 An example of a gutter guard installed on a gutter [15].

Patent EP3722531B1 is a European patent claiming a long pole with the motor at the end of it as seen in Figure 1.4 below [18].

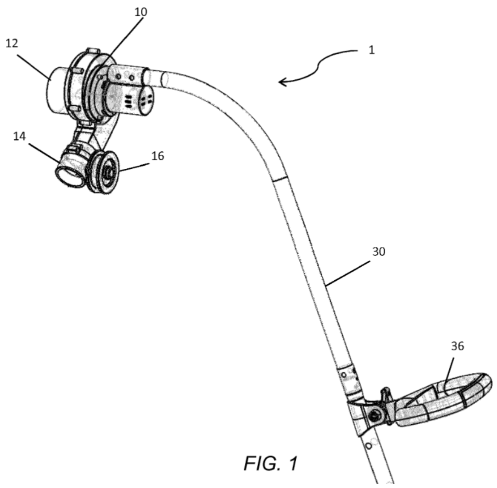


FIG. 1

Figure 1.4 Figure 1 pulled from Patent EP3722531B1 depicting the gutter cleaning device with a motor.

This device presents itself as a great way to clean gutters. However, in reality, the motor would add lots of weight at the end of the stick. This would cause the device to be too heavy for the customer to use, creating safety both for the user and home.

The Gutter Viper is the solution to all of the disadvantages of the other products: it is compatible with most household items, requires no ladder, and is light and portable. However, the price point of the Gutter Viper isn't competitive in the current market. As a result, our team has decided to redesign the Gutter Viper for cheaper manufacturing and assembly costs.

We have worked with Professor Ashton-Miller to understand the current manufacturing processes with the device and come to the conclusion that the Gutter Viper is over engineered [4]. The curved hose attaches to the sled via an extreme glue as seen in Figure 1.4. Because the curved hose and sled are not made out of the same material, it requires a unique glue in order to fuse them. Additionally, with this need to glue the pieces together, the assembly cost skyrocketed.

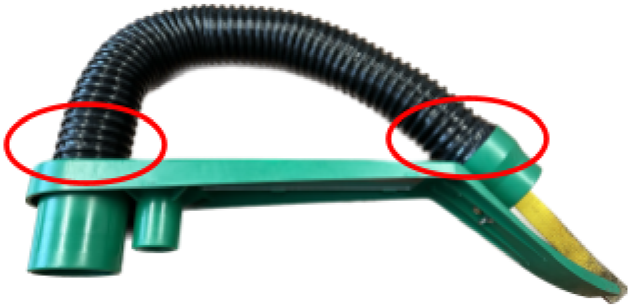


Figure 1.5 This demonstrates where the curved hose attaches to the sled via glue.

The sled, as mentioned before, is made of ABS and costs about $9.50 to produce [3]. The part itself is sturdy and can withstand all the forces on it from the leaf blower. However, as pointed out by Professor Ashton-Miller, the sled does not need to be as durable as it currently is [4]. There is potential for the

Gutter Viper to work as well with less sturdy material which could allow for a cost decrease whether that comes from a change in material or manufacturing process.

Our team was able to corroborate with this statement when we went to test out the Gutter Viper ourselves as seen in the Image 1.4 below.

Image 1.4 Team member Max Mancini cleaning the gutters at Professor Ashton-Miller's house using the Gutter Viper.

While testing out the Gutter Viper, we were able to identify some functional deficiencies which we plan to address in our design phase of this project. Moreover, when we redesign the Gutter Viper, we need to keep in mind typical limits for the human body. While there are no specific standards for lifting objects, the National Institute for Occupational Safety and Health (NIOSH) created a lifting equation that assesses the manual risks associated with lifting and lowering [6]. When inputting the parameters for cleaning gutters using the Gutter Viper, we found that a person must not lift an object exceeding 35lbs. Since the Gutter Viper is extremely compact and currently weighs less than 3lbs, we believe that we will easily accomplish this.

Overall, the Gutter Viper has potential to become a game changer in the gutter industry both for homeowners and cleaning contractors. It is the price point and some minor design changes that are stopping it. This semester, we plan on evolving this device to become the best that it can be.

SECTION 2: Design Process

The design process we have utilized so far is problem oriented and combines attributes of stage- and activity-based models [19]. The first consideration we made regarding which design process model to use was if a problem- or solution-oriented approach would be best. Considering that the original Gutter Viper constitutes a fully developed solution, a solution-oriented approach would make sense. However, in refining our problem statement the scope of our project expanded from focusing on the initial solution to focusing on the problem it was intended to solve - cleaning gutters. As a result, we decided to follow a problem-oriented approach.

Next, we determined that our approach should be both stage-based and activity-based. Stage-based methods mesh well with the ME450 class format, as landmark assignments are conducive to completing stages in a linear fashion. Our approach will start to be activity-based (cyclical) when we start ideating solutions. Our focus on reducing the cost of manufacturing will require considerations for both the product design and manufacturing process. This means we might pick a new manufacturing process and develop a design which matches it well, or develop a new design and pick a manufacturing process based on that. We will go back and forth between these activities until a solution is found which is feasible to manufacture and reduces cost.

Our design process so far has consisted of problem definition, stakeholder analysis, and generation of user requirements and engineering specifications, which have all been completed in stages following this order to align with course deadlines. However, we will continue to iterate on all of these steps throughout the semester. Going forward, our design process will include concept generation, concept development, prototyping, and testing.

Our design process thus far holds some similarities and differences to the ME Capstone Design Process. First, they are similar in the way they both combine aspects of activity- and stage-based models and are both problem-oriented. However, they are different because the ME Capstone Design Process is a higher level view. While our team has conducted stakeholder analysis as a distinct stage of our process, the equivalent in the ME Capstone Process is not explicitly included or may be included in the activity section with Stakeholder Engagement.

SECTION 3: Design Context

Throughout our project we have and will have many stakeholders to consider. The stakeholders that will have the most influence on our design choices, the primary stakeholders, consist of Professor Ashton Miller, homeowners, and gutter cleaning services. As the original designer, inventor and owner of the Gutter Viper business, Professor Ashton Miller's knowledge and subject expertise will be substantially influential to our project development. He knows the faults of the current Gutter Viper and where it succeeds, so any advice from him will be very useful. Professor Ashton-Miller also holds this project in high regard, as most of his research consists of studying elderly slips, trips, and falls[9]. Keeping people from falling is a high priority for him.

The other primary stakeholder is the average homeowner as they are the primary intended customer of this product. We have to consider them throughout the project so that we have a helpful product that almost every homeowner can use. The Gutter Viper is very effective at cleaning gutters, and typically only fails from user error. Therefore, we have to consider ways to make it more user friendly and employ strategies for easy instruction for the end user. Although gutter cleaning services may benefit from the status quo, they may also benefit from the Gutter Viper by using it commercially. In order to be beneficial for both homeowners and cleaning service companies, the assembly of the Gutter Viper on the user end will need to be quick and easy.

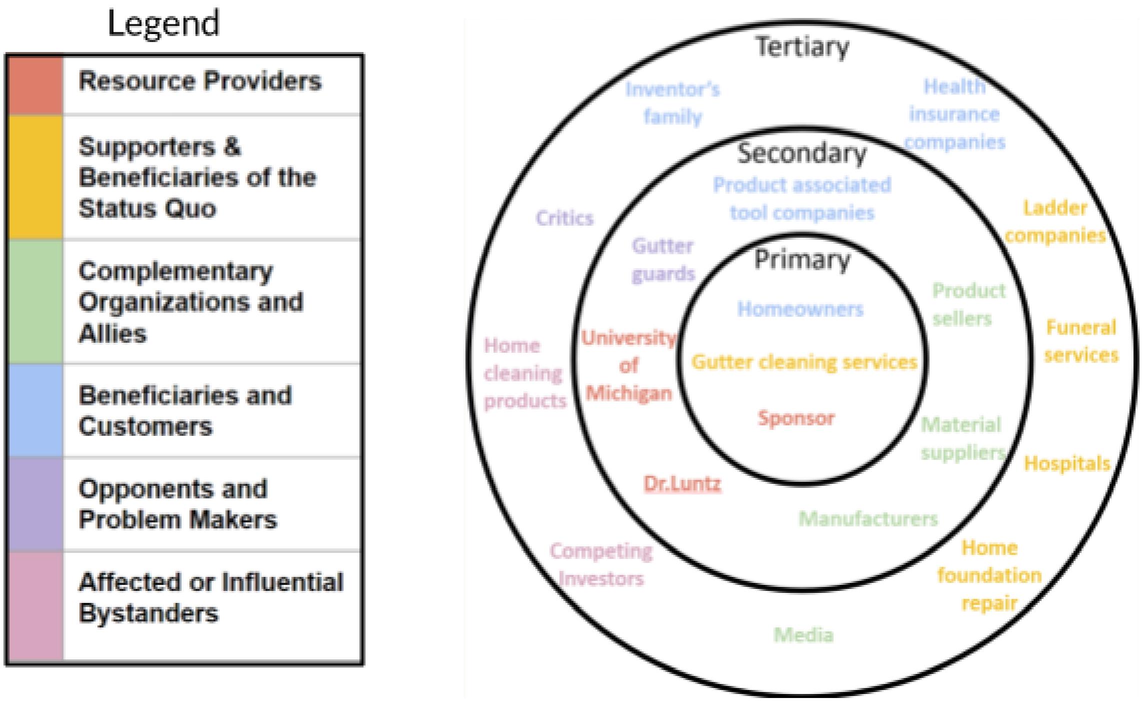


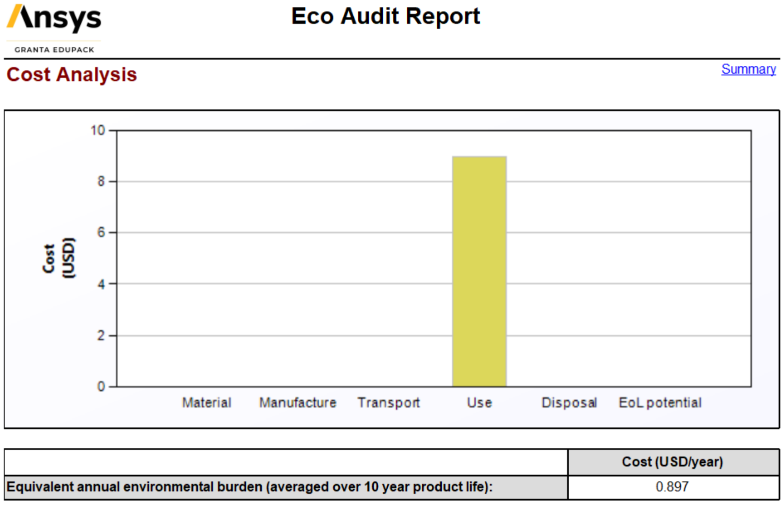
Figure 3.1 Stakeholder map consisting of the categories listed in the legend which are organized by their level of influence on the project. The more influential, the closer the stakeholder is in the center of the map [12].

The Gutter Viper was originally created because Professor Ashton Miller saw that most gutter cleaning methods are very dangerous. They involve either climbing onto the roof and leaf blowing at a high, uneven surface or using a ladder and manually scooping leaves from the gutter. Both of these methods are incredibly risky due to the high heights. Keeping homeowners on the ground will influence public health in a positive way by removing the need to be at high heights. This product will not only benefit the homeowner, but the Gutter Viper lowers the barrier to cleaning gutters for the elderly and disabled. Although the product is not intended for those who are less able bodies, it certainly is easier to clean gutters with than traditional methods.

There are some stakeholders that may not benefit from the mass use of the Gutter Viper. Small businesses, such as gutter cleaning companies or landscapers, could lose customers and profits due to homeowners cleaning their own gutters. Additionally, homeowners with functional gutters will have no damage to their home foundations. Therefore, contractors will also be losing business in the long term. And of course, any direct competitors that are producing gutter cleaners that work from the ground will be directly affected as the Gutter Viper is a cheaper alternative to most. Safety is the main motivation for the Gutter Viper, so although there are some stakeholders that will be hurt by the potential mass use of the Gutter Viper, people won't be getting hurt and that takes precedence in our decision making process.

The Gutter Viper will have some environmental effects, most of them are unfortunately negative. In order for it to be cheap to manufacture and then sell, the product must be made out of some plastic. Although not exactly a sustainable material, it will last a long time and provide strength to the Gutter Viper to clean effectively. Also when compared to other gutter cleaning products, it uses less new material since one can use other common household tools (painters stick and leaf blower). The average homeowner who typically does their own yard maintenance will already have these, preventing new items from being made. Other gutter cleaning products that use plastic tubing and even whole motors have a significant amount of new unsustainable materials that the Gutter Viper does not have. The plastic from the Gutter Viper will also not be infinitely recyclable. Disposing of it will mean that it will end up in a landfill, but the goal is to have it be effective for at least five years making the usage outweigh the environmental costs. Another environmental consideration to make is the leaf blower needed to make the Gutter Viper work. For the most part, leaf blowers are very inefficient, but that choice to switch to a more efficient leaf blower is on the end user.

Furthermore, we recognize that there are some environmental costs associated with manufacturing the Gutter Viper product using injection molding. We anticipate that the annual power consumption will be most directly associated with running the gas/electric powered leaf blower to supply the recommended airflow to the device to clean gutters.



Eco Audit Report

Cost Analysis

Summary

	Cost (USD/year)
Equivalent annual environmental burden (averaged over 10 year product life):	0.897

Figure 3.2: CES eco-audit tool annual costs associated with Gutter Viper power consumption [23].

Using the CES eco-audit tool, cleaning your gutters 3 times a year, at 1 hour each day, using a 700W leaf blower, the total power consumption is ~57,500 kcal in usage over the expected 10 year lifespan of the product. This energy usage, assuming an electric leaf blower, translates to an annual cost of \$0.90/yr. These costs represent the total environmental costs associated with the production and use of this product.

The total annual recurring costs for energy and environmental cost consumption includes:

P = (.90+.33)*[((1+.04)^10 - 1)/(.04*(1+.04)^10)] = **\$9.98**

Therefore, we can expect consumers to spend roughly ten dollars annually on using the leaf blower with the Gutter Viper to clean their gutters. We would expect similar annual cost results for gas powered leaf blowers too. While we recognize that this preliminary LCCA shows some association with power consumption and environmental costs, we think that the significant reduction in homeowner risk by keeping people on the ground and off ladders is entirely worth the cost. In addition to manufacturing being done in the United States, we believe this is an ethical product that will provide a greater net positive for society's quality of life.

The intellectual property of the Gutter Viper will have a large impact on the design choices that need to be made. Currently, Professor Ashton Miller and Jeffery Terrel are the utility patent holders of the Gutter Viper. With this patent in mind, we have two options: change the design to decrease the manufacturing cost and create a new design patent, or we can create a new utility patent if the design choices change the utility of the product. A redesign and new design patent mean that the main claims of the Gutter Viper must stay. This limits the amount of leeway we have with the features of the product, potentially hindering some cost saving factors (like removing the "tongue" or leaf agitator). If a new utility patent was in consideration, much more research would need to be done to ensure that every aspect of the new design would not infringe on other patents.

SECTION 4: User Requirements and Engineering Specifications

Our requirements are derived from both our problem statement and the existing Gutter Viper. The first three requirements regard the functional capability to clean gutters, the ability to operate from the ground, and low cost. These requirements are considered our highest priority because they are the most important to our sponsor and parallel our problem statement directly. The following requirements draw relevance from the comparison to the current Gutter Viper – our goal is to come up with a solution which improves upon the existing design, so our engineering specifications are based on the current Gutter Viper's performance.

First, cleaning gutters and operating from the ground are the two main functions of the Gutter Viper. These metrics will evaluate the Gutter Vipers effectiveness to perform preventative maintenance by cleaning all dry leaves from gutters. Moreover, we decided that 20ft reach compatibility, in addition to typical human heights, would be sufficient enough to clean second story gutters, thus accommodating the majority of homeowner's residences.

The main scope of our project is to reduce the Gutter Viper's production cost, which includes all material costs to produce one Gutter Viper unit. We have been tasked with decreasing the overall production cost to 10% of the suggested retail price of $115. Therefore, we see it fit to achieve this goal in parallel with decreasing the assembly/labor costs associated with producing one Gutter Viper unit. We believe that an overall cost to produce one unit under $25 will provide a competitive price point for our sponsor to make a profit as well as a low price for consumers to acquire the Gutter Viper. Additionally, it is imperative that the consumer not need to purchase additional products to use the Gutter Viper. Therefore, in the hopes of maintaining the goal of a low cost solution, we would like to promote compatibility with the majority of leaf blowers on the market today, which were mostly found to be within a 6" blower diameter outlet. Moreover, we sought it best to maintain the current recommendations of 250 CFM to maintain product functionality and effectiveness.

After initial testing of the Gutter Viper, we found some improvements that can benefit the user. First, we thought the weight was manageable to control, and therefore are not concerned with increasing the product weight up to 120% of its original weight. It is important to note that this weight increase would have to warrant some quantifiable benefit; product functionality improvement or cost reduction. Additionally, we thought the user assembly of the airtube and Gutter Viper tool was manageable. Therefore, we would like to maintain or slightly increase the level of assembly required by offsetting some of the assembly costs to produce the product to the end user. We think we can mitigate cost while maintaining ease of product assembly by establishing reasonable assembly metrics, such as the use of less than three tools, and a total assembly time of less than five minutes. Furthermore, we found that the abs material used to manufacture the Gutter Viper survived an accidental drop test from high heights. We would like to maintain such durability in the likely event an end user were to drop the product while cleaning gutters. We decided that a pass/fail fracture drop test would be the best design metric, since it is hard to exactly quantify fatigue testing, which is highly dependent on end user product usage.

Moreover, we found that the mirror serves a verification purpose for the user to ensure their gutters are in fact clean of leaves and debris, and would like to maintain this current feature size of 2x6”, which was more than sufficient to see into the gutter. We would like to potentially decrease the overall size of the Gutter Viper to mitigate shipping costs and increase storability, and decided that a standard shipping box size of a 20”x12”x4” would be reasonable.

As is discussed later in Section 8, preliminary engineering analysis has revealed that outlet velocity calculated using CFD is not a sufficient measure of performance to our requirement “Cleans Gutters.” Therefore, the specification has been modified to include that mass flux at the outlet must be uniform (qualitatively determined using CFD) and the force exerted by the air must be at least 90% of that from the original Gutter Viper (requires real-world testing).

Throughout our concept generation process (to be mentioned later), we took careful consideration in determining the factors that are important to improving the Gutter Viper. This led us to the conclusion that all of the concepts generated for the requirement of “air tube doesn’t kink/twist” were too expensive and difficult to manufacture for small functionality benefit. When we tested out the original Gutter Viper, it rarely hindered the functionality, and if it did it was a quick fix. The overall manufacturing costs heavily outweighed the small improvement so we decided upon removing that requirement.

The table on the following page demonstrates how our requirements and specifications relate to performance of the existing solution and provides possible ways we can test our design and compare it to the Gutter Viper.

Table 4.1 Requirements and specifications of the new Gutter Viper. This table includes how we are going to measure and test them.

Requirement	Specification	Original Gutter Viper	How to Test
Cleans Gutters	Uniform mass flux at outlet Force exerted on a 4" x 4" plate at a distance of 6" > 90% original	Cleans all dry leaves	- CFD analysis - Build scale fixture
Operate from the Ground	Can extend from leaf blower at least 20 feet	Includes 20 ft air tube	- Measure reach length
Low Cost	Unit Cost + Labor Cost < $25	- Unit Cost is $21.05 - Labor Cost is $40	- Get manufacturing quotes
Compatible	- Fits blower diameters up to 6" - Effectively cleans with minimum airflow of 250 CFM - Fits ¾ x 5 ACME painter stick - Fits in standard gutter: 5" wide	- Fits blower diameters up to 6" - Effectively cleans with minimum airflow of 250 CFM - Fits ¾ x 5 ACME painter stick - Fits in standard gutter: 5" wide	- Measure performance to other specifications at 250 CFM - Test fit up to 6" blower diameters - Test fit ¾ x 5 threads - Test fit in standard gutter
Low Weight	Weighs < 120% of original weight	Weighs 1.5 kg	- Use CAD model volume and density - Mass prototype with scale
Easy to Assemble for End User	< 3 connection points < 3 tools Takes < 5 minutes	- 3 connection points - 0 tools	- Yes/No
Durable	- Doesn't fracture from 20 ft drop - Made of corrosion-resistant materials	- Doesn't fracture from 20 ft drop - ABS & stainless steel	- Drop on concrete from 20 ft - FEA impulse associated with 20 ft drop
Compact	- Fits in 20"x12"x4" box (including air tube, tools, instructions, and product)	- Assembled dimensions 16"x8"x4" - Shipped in 20"x12"x4" box	- Measure CAD model
Able to view inside of gutter	2"x6" or larger mirror fixture on the underside	2"x6" Mirror Size	- Included Yes/No
Instructional aid/controllable	Include instructional video/card	Large instruction card, issues with users not figuring out nuances	- Included Yes/No

SECTION 5: Concept Generation and Selection Process

Because the nature of our project is a redesign, our group took an unconventional approach to concept generation and selection. The concept generation and down selection happened as an iterative process together; therefore, combining these sections made the most sense as both build off each other. Our overall process follows function decomposition to justify the current path of action, subfunction breakdown of each part of the Gutter Viper, concept generation for each subfunction, and finally, down selection using a Pugh Chart.

When we first started exploring different concepts for the Gutter Viper, we wanted to make sure that continuing the leaf blower attachment was the correct way to go. In order to justify that, we made a function decomposition of cleaning gutters from roofs. We made certain assumptions that it had to be from the ground as that ecompasses the scope of our project. Figure 5.1 on the next page shows the map that we created.

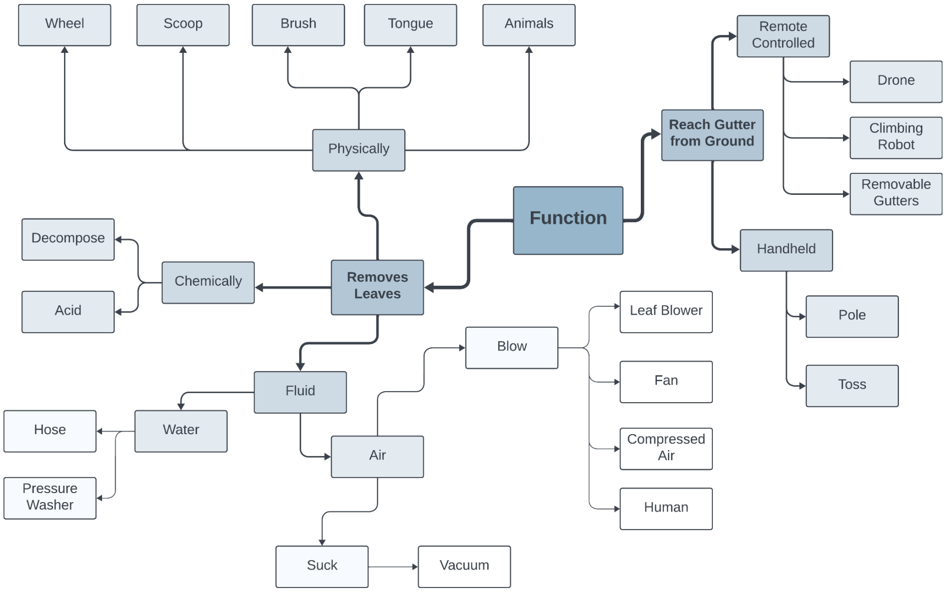


Figure 5.1 Functional decomposition illustrating entire solution space for cleaning gutters from the ground.

When breaking down the functions, we started with two main groups: remove leaves and can reach the gutter from the ground. Since these were the main focus of our project, this made the most sense to us. From there, we were able to break down removing leaves into removing them physically, chemically, and with a fluid. For physically removing leaves, we chose scoop and tongue in order to sustain the original patent of the Gutter Viper as these were part of the main claim. Next, we decided to completely get rid of chemically removing leaves as this device is going to be a safe alternative and chemicals are rarely safe for general users. Finally, in the fluid group, we broke that down to using either air or water. We were able to eliminate hose as we did not think it was powerful enough to clean leaves in the manner we wanted it to and also eliminate pressure washer as it was not a common enough tool. Additionally, air blows the leaves out of the gutter while using water to clean gutters, it pushes leaves to the end of the gutter, causing clogging. Since we want to maximize the effectiveness of the product, we stuck with air. When breaking down air, we finally narrowed it down to a leaf blower as that was the best combination of enough force with common appliances. When breaking down reaching the gutter from the ground, we removed any remote controlled option as that would add motors which intern add expenses; since this needs to be a low cost device, it made the most sense. We finally chose a hand held pole option as that would have better accuracy over a throwing device. This function decomposition helped to determine that the best solution was a form of the current one.

From there, we wanted to identify the most important elements of the Gutter Viper that could be iterated on to create alternate solutions. As seen in figure 5.2 on the next page, we were able to break down the device into 6 different components: device inlet to outlet connection, leaf blower outlet to device inlet connection, support pole connection, scoop attachment, and tongue concept and attachment.

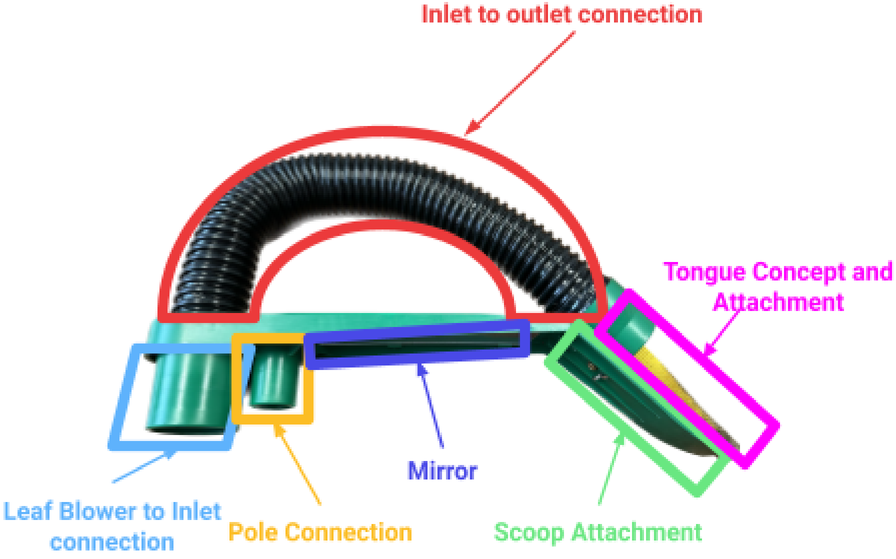
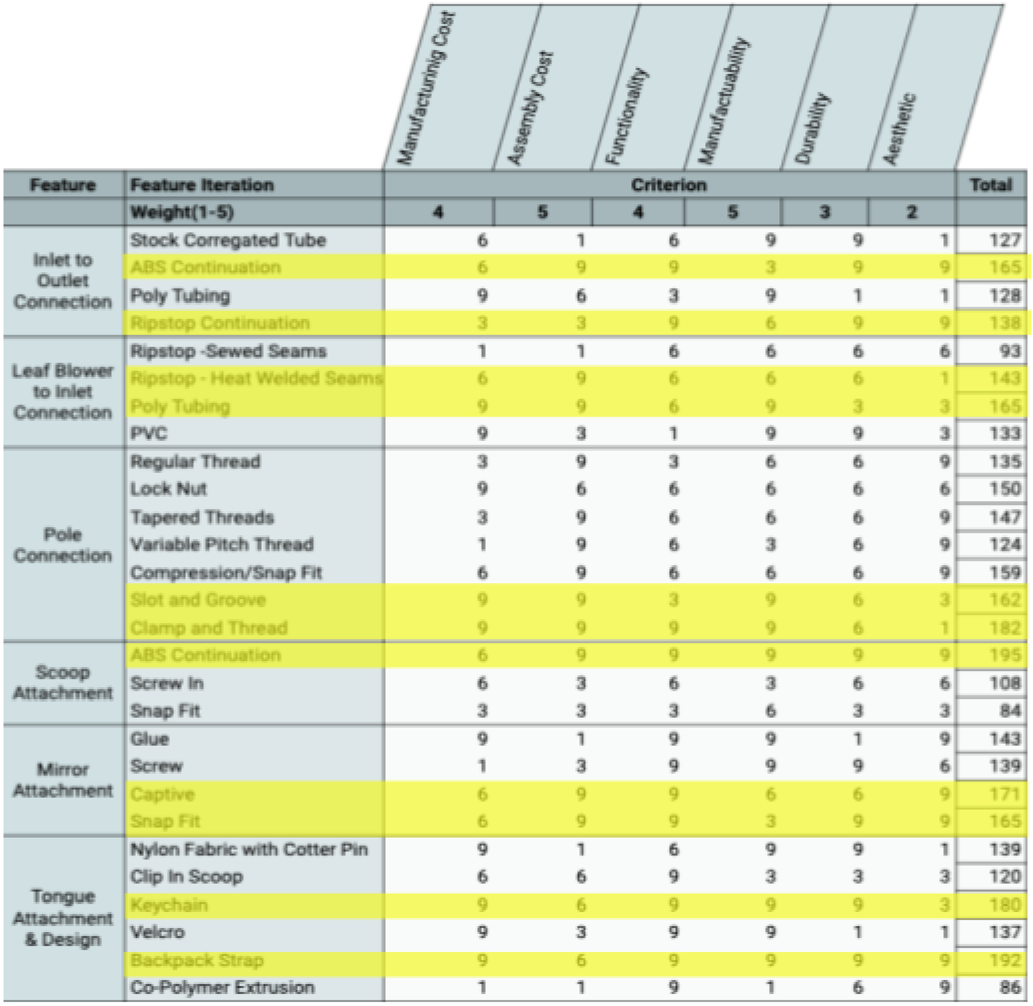


Figure 5.2 The breakdown of the different components of the Gutter Viper.

We then created multiple solutions to each of the features as a team. Some of these ideas came from the Concept Generation Learning Block and others came from brainstorming sessions we had together. A lot of ideas could be removed before the down selection concept because of their infeasibility. Such ideas can be seen in Appendix A. We then weighted each feasible solution for each feature against each other on a Pugh Chart with manufacturing cost, assembly cost, functionality, manufacturability, durability, and aesthetics as the categories. Using a 1-3-6-9 scale, and different weights for the categories based on importance, we found the top two winners of each component to use for our design. We decided to pick the top two as some of the solutions that we developed were coupled with other ideas from different components. While most of the ideas themselves were decoupled and independent, we wanted to make sure we were not going to be stuck with a non feasible device; therefore, picking the top two choices made the most sense. Additionally, because of the cost focus of our project, we wanted to create two designs in order to compare their price with manufacturers and suppliers. Some solutions have an unclear price point on their addition to the overall device, so having two designs would allow us to identify the lowest cost solutions with the best functionality. Figure 6.3 on the next page is the Pugh Chart of all of the components and their solutions.



		Manufacturinig Cost	Assembly Cost	Functionality	Manufactuability	Durability	Aesthetic	
Feature	**Feature Iteration**	**Criterion**						**Total**
	Weight(1-5)	**4**	**5**	**4**	**5**	**3**	**2**	
Inlet to Outlet Connection	Stock Corregated Tube	6	1	6	9	9	1	127
	ABS Continuation	6	9	9	3	9	9	165
	Poly Tubing	9	6	3	9	1	1	128
	Ripstop Continuation	3	3	9	6	9	9	138
Leaf Blower to Inlet Connection	Ripstop -Sewed Seams	1	1	6	6	6	6	93
	Ripstop - Heat Welded Seams	6	9	6	6	6	1	143
	Poly Tubing	9	9	6	9	3	3	165
	PVC	9	3	1	9	9	3	133
Pole Connection	Regular Thread	3	9	3	6	6	9	135
	Lock Nut	9	6	6	6	6	6	150
	Tapered Threads	3	9	6	6	6	9	147
	Variable Pitch Thread	1	9	6	3	6	9	124
	Compression/Snap Fit	6	9	6	6	6	9	159
	Slot and Groove	9	9	3	9	6	3	162
	Clamp and Thread	9	9	9	9	6	1	182
Scoop Attachment	ABS Continuation	6	9	9	9	9	9	195
	Screw In	6	3	6	3	6	6	108
	Snap Fit	3	3	3	6	3	3	84
Mirror Attachment	Glue	9	1	9	9	1	9	143
	Screw	1	3	9	9	9	6	139
	Captive	6	9	9	6	6	9	171
	Snap Fit	6	9	9	3	9	9	165
Tongue Attachment & Design	Nylon Fabric with Cotter Pin	9	1	6	9	9	1	139
	Clip In Scoop	6	6	9	3	3	3	120
	Keychain	9	6	9	9	9	3	180
	Velcro	9	3	9	9	1	1	137
	Backpack Strap	9	6	9	9	9	9	192
	Co-Polymer Extrusion	1	1	9	1	6	9	86

Figure 5.3 The Pugh Chart of all of our potential solutions for the different features of the Gutter Viper. The highlighted solutions are the winner based on their overall score on the right. Each feature iteration is only weighted against other iterations of the same feature. We selected the top two feature iterations with the highest scores of each feature category to be turned into our two final designs.

After identifying the top two winners, we were then able to create them in detail. The next section goes into depth about the advantages and disadvantages of each of the winners.

SECTION 6: Selected Concept Description (the "Alpha Design")

For the alpha design, we created our top two designs for the Gutter Viper redesign based on mitigating production cost by drastically reducing the total number of components and minimizing the amount of assembly needed. Each design, as shown below in Figure 6.1, is the final overall design that will incorporate an accumulation of the cheapest and most efficient sub function design, which will be evaluated independently. At this point in the design process, we do not have enough information from suppliers to select the better design. Therefore, we will continue to develop both designs as we work with industry professionals to identify the solutions proven to be of the highest quality and lowest cost.

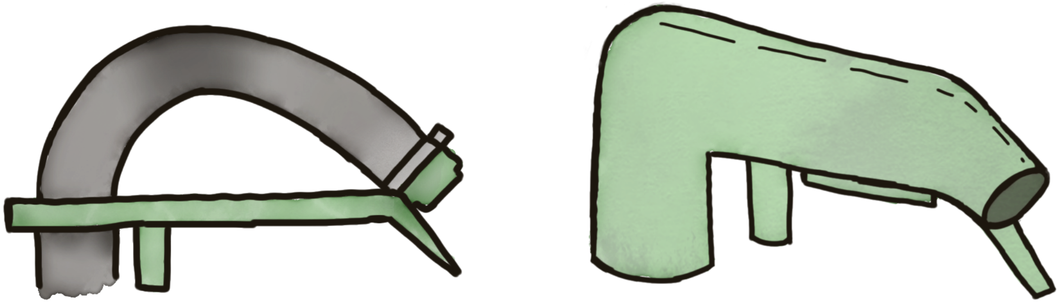


Figure 6.1: Top two alpha designs currently being considered. Idea #1 (left) showing ripstop continuation of flexible air tube. Idea #2 (right) showing abs continuation of rigid air tube.

Idea #1 is visually very similar to the current Gutter Viper product. However, the continuation of the ripstop nylon tubing from the tool inlet to the outlet is expected to significantly reduce the current product cost by eliminating the stock corrugated tubing as well as the gluing associated with the assembly. One potential concern with this idea is how the shape and geometry of the flexible tubing will maintain its structure between the inlet and outlet as it redirects airflow. Idea #2 is combining the structural and airflow redirection components of the current Gutter Viper product, and redesigning it into one, assembled component. We anticipate being able to injection mold (using abs material) this design into two halves split down the length of the tool, as shown by the cross sectional view in Figure 6.2 below.

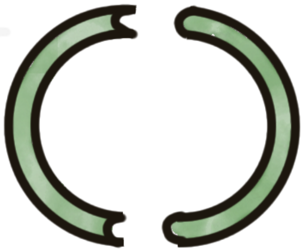


Figure 6.2: Tongue and groove assembly method associated with Idea #2 via a two piece injection molding manufacturing method.

Assembling the two piece injection molded product by a glue line between the tongue and groove would significantly reduce the assembly cost of the current product by eliminating the total number of components, such as the need for a threaded insert and screw assembly.

Based on the results of the Pugh Chart above, we identified the top two scoring sub function designs for most of the relevant features on the Gutter Viper. Since some of these sub functions are coupled and dependent on other sub functions or overall alpha design, we found it best to evaluate each sub function design independently.

Leaf Blower to Inlet Connection

Two different materials were considered for flexible blower to tool inlet connections. We think flexibility is advantageous for efficiency in product shipping and storage, as well as accommodating various gutter heights. We were motivated to maintain the current functionality of the flexibly ripstop nylon tubing, but decrease the associated high assembly cost to sew the fabric. Figure 6.3 below shows the Ripstop nylon fabric using heat welded seams to mitigate assembly cost of the airtube, in addition to stock plastic poly tubing that the user can cut to length.

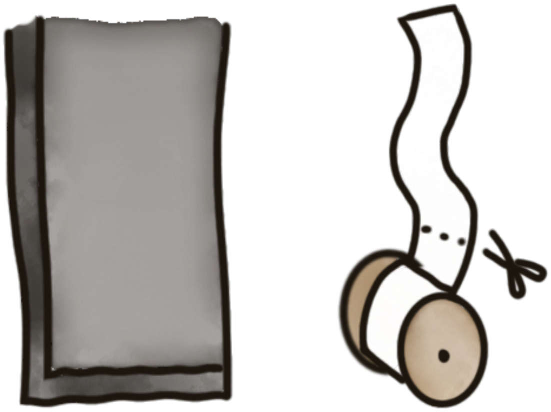


Figure 6.3: Ripstop Nylon fabric assembled via heat welded seams (left) and poly tubing (right).

Through testing, we found that the sewn seam for the Ripstop nylon tube ripped, and therefore is an expensive, non-durable solution. Therefore, we investigated heat welded seams as an assembly method to improve durability and reduce assembly cost. The original Ripstop tube tore around the seam of the tube, so the material has a weak point around the seam. Heat welded seams will prevent this (by not creating a hole in the fabric with a needle) and speed up manufacturing time and therefore cost. Poly tubing has its pros and cons as well. There are concerns over the durability of the plastic so we will have to get a sample of it to test it out. If durable it can be a really effective solution due to its low cost and minimal labor needed (just cutting at one end). The poly tubing cannot be used if the ripstop continuation concept is chosen because there is no way to fix it to the inlet.

Mirror Attachment

We identified the importance and usefulness of the mirror as user verification to ensure leaves are in fact being removed from the gutters. However, we recognize current product complaints of poor adhesion leading to failure in the mirror bonding. We are investigating alternative ways to assemble the mirror to eliminate failure as well as decrease associated gluing assembly costs. Figure 6.4 below shows the two main mirror assembly methods we are considering; snap fit directly into the Gutter Viper, or captive within the Gutter Viper's assembly.

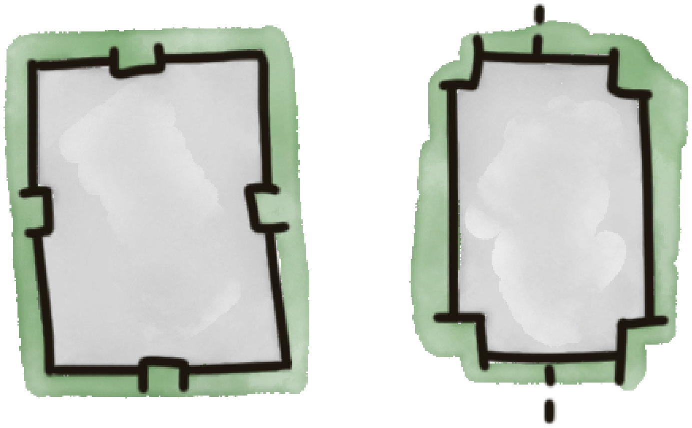


Figure 6.4: Snap fit mirror assembly (left) and captive mirror assembly (right).

One concern we have with snap fit is long term durability, the mirror falling out etc. With the captive mirror, the ABS continuation concept must be chosen for it to work. This is because the two halves of the mold will allow the mirror to actually be captive. Since there is no gluing involved, the labor costs for this portion of the Gutter Viper should be significantly decreased.

Tongue Connection

As part of honoring the IP agreement of the current Gutter Viper utility patent, we need to maintain the assembly of the tongue as the leaf agitator. However, we identified the current cotter pin assembly method is non-aesthetically unprofessional and looks quite cheap. Therefore, we investigated alternative ways to assemble the viper's tongue. Figure 6.5 illustrates the two different attachment methods we considered for a stock strap leaf agitation tongue; using a keychain clip to loop through both the tongue and the Gutter Viper, or a backstrap type strap adjuster connection where the tongue itself loops through the top of the Gutter Viper.

Figure 6.5: Keychain tongue assembly method (left) vs backpack strap friction tongue assembly method (right).

Pole Connection

After some initial testing, we found that the threaded pole connection worked well for the recommended Mr.Long Arm painters pole because of the built in locking mechanism. However, the friction provided by the threaded connection alone was insufficient when utilizing a general household painters pole, causing the Gutter Viper to come loose and resulting in the user losing control. Therefore, we are investigating ways to maintain the compatibility with existing household painter poles by adding a locking mechanism to the threaded connection, such as an additional hose clamp or lock pin, as illustrated in Figure 6.6 below.

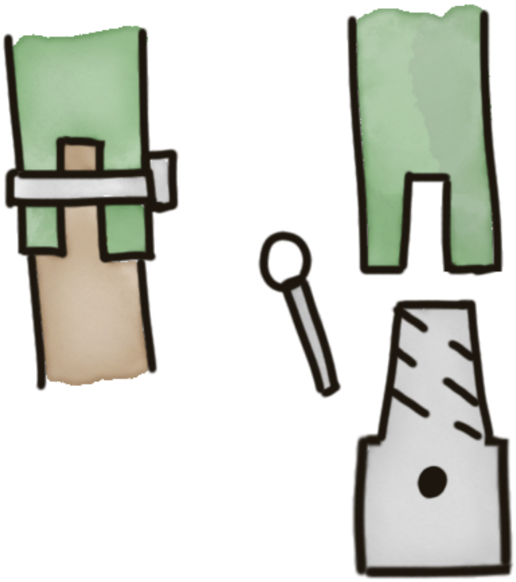


Figure 6.6: Support pole connection method using threads with hose clamp assembly (left) and tapered threads with lock pin assembly (right).

Updates Since DR2:

We left off with many decisions to make for our final design. Our biggest one was the outlet to inlet connection because many of our ideas were coupled to which idea we chose. Due to this concept being difficult to evaluate at a surface level, we decided to pursue both options to truly evaluate which one would be “best”. The “best” one will likely be subjective as aesthetics do play a role in the product that we are making and is ultimately not up to us. By pursuing both, we can verify functionality and cost of both and have Professor Ashton Miller have the final say. Because we chose both the ripstop and ABS continuation for the inlet to outlet connection, the coupled ideas above must be chosen as well. The snap fit mirror is for the ripstop continuation and the captive mirror is for the ABS continuation.

For the decoupled ideas, we decided that the simplest concept would be best. For the tongue connection, it can be reasonably argued that the less parts needed to assemble, the better. This will make it cheaper not only for the cost of the part but also the assembly time. For the pole connection, we decided to have the same connection as the original Gutter Viper, but now just include another hose clamp. This is a cheap solution for twisting problems and it doesn’t require the end user to buy the extra part for the slot and groove option. We can still offer up this as an option if Professor Ashton Miller deems it as necessary. For the leaf blower to inlet connection, we discovered in a meeting with Professor Ashton Miller that he had already considered poly tubing as a solution, but decided against it because another patent had used poly tubing. Since he did not feel comfortable with using poly tubing before, we decided to pursue the rip stop tube option.

SECTION 7: Engineering Analysis

First, we tested different flexible ripstop nylon tubing shapes to observe which design would yield the best results in airflow at the device outlet, in addition to yielding the most aesthetically pleasing and professional looking product for our ripstop continuation prototype. As shown in Figure 7.1 below, we sewed three different ripstop tubing designs: straight tube, curved tube, and tapered tube.

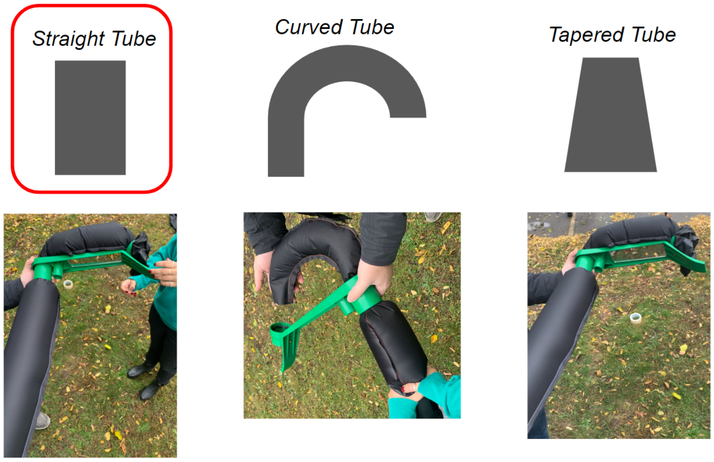


Figure 7.1: Straight, curved, and tapered Nylon tubing designs.

We observed that all three Nylon tubing designs yielded similar results in outlet airflow. Furthermore, we noticed that the smaller diameter tubing, such as in the curved Nylon tube design, appeared to be more aesthetically pleasing. However, because our main goal is to reduce manufacturing costs, we decided to pursue the straight tube design for the ripstop continuation prototype. We predict the simplest design will be the cheapest to sew and assemble the Nylon tubing. Additionally, we plan on making this design more aesthetically pleasing by making the diameter of the airtube to match that of the inlet of the Gutter Viper device it is inserted into. We also plan on adding slots to the nozzle of the Gutter Viper to tuck the free end of the Nylon tubing under the hose clamp to give a cleaner overall product look.

Next, we verified the ability to maintain original product functionality for our two prototype designs by performing airflow testing. We created two prototypes to simulate the two final designs we are pursuing. First, for the ripstop continuation prototype, as shown to the left in image 7.2 below, we utilized the sled of the original Gutter Viper and ran the ripstop tubing through the inlet of the device to hose clamp to a custom, 3D printed nozzle, which we attached to the sled via zip tie. Next, we simulated the abs continuation prototype, as shown to the right in image 7.2 below, by gluing together a 90 degree elbow stock to a nipple, which then connected to a 45 degree stock tube, all of which made of PVC pipe.

Figure 7.2: Ripstop continuation prototype (left) and abs continuation prototype (right).

Once we built our prototypes, we performed a robust empirical experiment to evaluate the ability said prototypes to maintain current Gutter Viper functionality. Because our budget prevented us from acquiring a flowmeter that could measure the high CFM airflow experienced at the device outlet, we performed an empirical “ball float” test to compare the airflow velocity at the outlet. First, we connected each design inlet to the airtube, and then the airtube to the leaf blower via hose clamps, making sure the airtube was straight during the entirety of the test to prevent any kinking that may hinder airflow performance. Next, we turned the device upside down, and turned on the leaf blower, throttling at a consistent speed. Finally, we carefully placed the ball over the outlet of the device and recorded the height the ball was able to float up to and maintain.

The goal of this test was to verify our prototypes would float the ball at a higher or equal height than the current Gutter Viper. This would ensure that the outlet velocity is the same, thus preserving the ability to effectively clean dry leaves. As shown in Figure 7.3 below, both prototype ball heights were equal to or larger than the ball height achieved from the original Gutter Viper.

Original

ABS Continuation

Ripstop Continuation

Figure 7.3: A very excited Max Mancini seen performing ball float tests for the original Gutter Viper (left), the abs continuation prototype (center), and the ripstop continuation prototype (right).

More specifically, Figure 7.4 quantifies the ball heights achieved by the original product in addition to the prototypes. The ball height was evaluated by referencing the diameter of the ball used to be 2.9 inches (representative of a standard pickleball) to the device outlet.

Original **ABS Continuation** **Ripstop Continuation**

Figure 7.4: Original Gutter Viper ball height of about 11.6 in. (left), abs continuation ball height of about 20.3 in (center), and ripstop continuation ball height of about 11.6 in.

It is important to note that there are some levels of error during the ball float empirical testing that may have influenced our results. First off, the abs continuation, being a prototype made of PVC, does not have a sled attached to its outlet. In the other two designs that contain a sled, the sled itself curved up and into the path of airflow. Therefore, we expect the PVC prototype yielded the best performing results because it did not contain any restrictions to the airflow at the outlet. In order to overcome this not so perfect apples to apples comparison, we plan on re-performing this test with a 3D printed model of the final abs continuation prototype to yield more realistic results. Moreover, the leaf blower utilized did not contain any "set" airspeed settings, and we therefore recognize the throttling of the leaf blower airspeed may yield some levels of human error in our results. All in all, we concluded that both prototypes maintained or improved current product functionality.

In order to accurately evaluate the cost reduction in assembly for our new prototypes, we empirically performed labor tests to gather the assembly times for each prototype. We performed four trials for each the original Gutter Viper, the abs continuation prototype, and the ripstop continuation prototype. As shown below in Figure 7.5, one can see team member Holden Collins assembling the ripstop continuation prototype. To make these tests as realistic to the same conditions a laborer would be under, we separated each part into different bins around the room. Since this is also manufacturing assembly, and as such a laborer would be doing the task repeatedly, we practiced the assembly process a few times for each design to improve our efficiency.

Figure 7.5: Holden Collins graciously assembling the ripstop continuation prototype

We expected that our assembly times would be much less to that of the original assembly, and therefore decrease costs because our prototype designs used significantly less parts and easier assembly methods. For example, the original Gutter Viper used a threaded brass insert with a screw and a lock nut to attach the nozzle to the sled, whereas our designs just used a zip tie to attach both parts together. Furthermore, the original design required the laborer to glue and hold the corrugated stock tube into place, whereas our ripstop continuation design offsets the assembly at the nozzle to the end user, completely eliminating the material and assembly cost. Additionally, our designs feature two slots at the nozzle outlet to assemble the nylon strap representing the viper tongue, in which the assembly is offset to the end user, completely voiding the cotter pin costs and assembly time associated with installing the tongue on the original Gutter Viper. Table 7.1 below illustrates our results in reducing the assembly times for our prototypes in comparison to the original product.

Table 7.1: Assembly times for the original Gutter Viper, the abs continuation prototype, and the ripstop continuation prototype for each team member: Max, Holden, Jackie, and Daniella. The assembly times for each design were then averaged.

Team Member	**Original [s]**	**ABS Continuation [s]**	**Ripstop Continuation [s]**
Max	9:51	3:00	0:59
Holden	8:48	2:32	0:58
Jackie	9:19	2:15	0:53
Daniella	10:06	2:20	1:32
Average	**9:31**	**2:42**	**1:05**

Table 7.1 demonstrates that by significantly reducing the number of parts and offsetting product assembly to the end user, the manufacturing related assembly for the prototype designs was significantly less than the original Gutter Viper assembly times.

We decided to use zip ties instead of the threaded insert and nut connection to connect the baseplate sled to the nozzle. This connection is not only easier to assemble, but costs significantly less. A zip tie costs roughly $0.03 cents per part and has an expected lifespan of 5-10 years [25].

SECTION 8: Build Design/Final Design Description

Build Design

Consistent with our plan to provide two options for a final design, our build design also consists of two detailed models. The first design, the ABS Continuation, is a single part which consists of a curved manifold which tapers gradually from a 4" inlet to a 2" outlet. A support structure with a rectangular cross section connects the exterior of the inlet and outlet, then tapers past the outlet to form the scoop. The support structure has 4 tabs on the bottom to capture the mirror. The outlet has two slots which allows a single strip of nylon webbing to enter from each side, forming two tongues with an outer loop laying flush on the outside. The back of the inlet has a boss which has ¾-5 ACME threads to fit a painter's pole. The Ripstop air tube fits around the inlet and is fixed with a hose clamp, then similarly to the leaf blower on the other end. Figures 8.1 and 8.2 show the CAD model of this design.

Figure 8.1: ABS Continuation Build CAD Model

Figure 8.2: ABS Continuation Build CAD Model

The second option, the Ripstop Continuation, consists of two parts: the sled and nozzle. The sled and nozzle each have two matching rectangular slots which allows them to be held together with a single zip tie. The sled consists of a frame which includes a 4” diameter loop the Ripstop air tube passes through, a boss with ¾-5 ACME threads for a painter’s pole, 4 snap fit features to affix the mirror, and a tapered scoop. The 4” loop has an additional hole which interfaces with a grommet on the air tube to prevent twisting. The nozzle is 2” in diameter, and in addition to slots for the zip tie, has two longer slots to attach the nylon webbing tongue. Figure 8.3 shows an assembly of the sled and nozzle, and Figures 8.4-8.7 show details of each part.

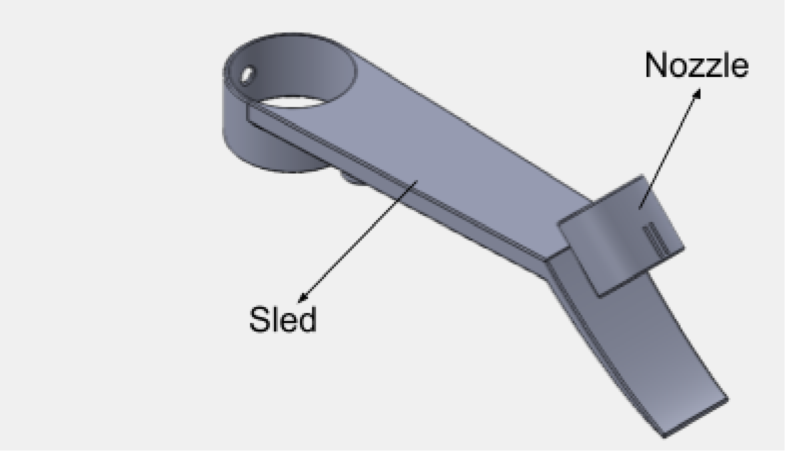


Figure 8.3: Ripstop Continuation Build CAD Model - Assembly

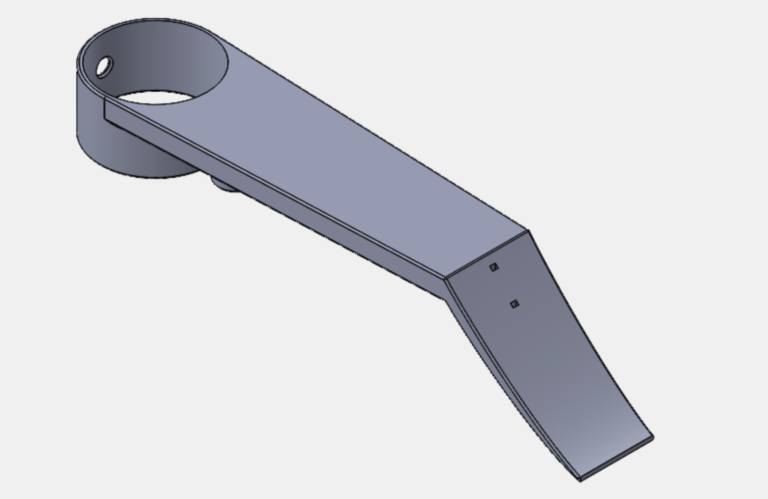


Figure 8.4: Ripstop Continuation Build CAD Model - Sled

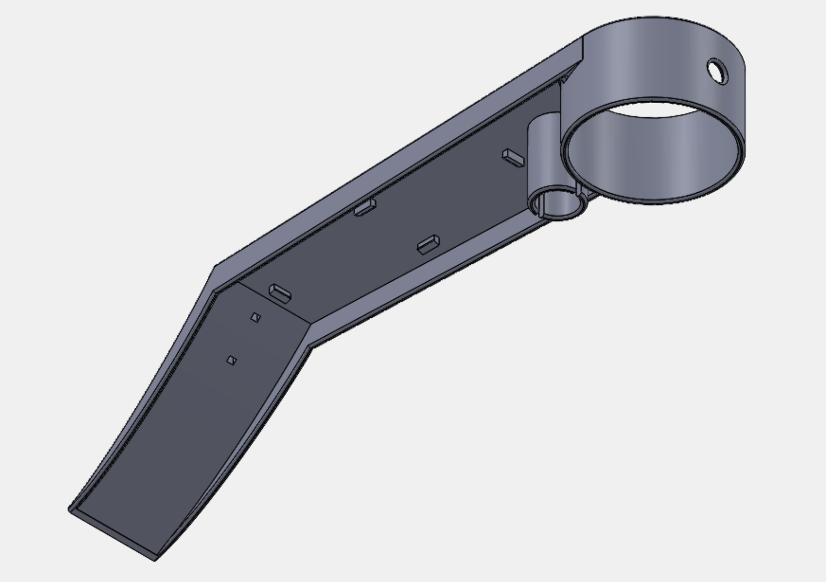


Figure 8.5: Ripstop Continuation Build CAD Model - Sled

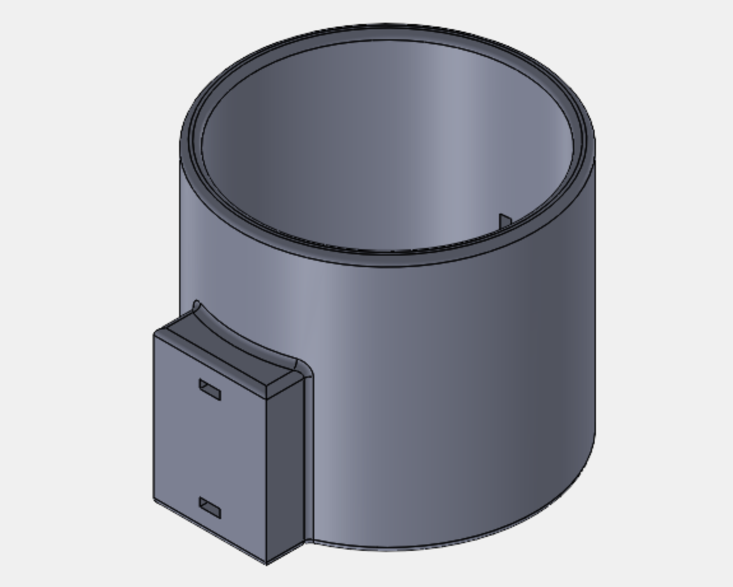


Figure 8.6: Ripstop Continuation Build CAD Model - Nozzle

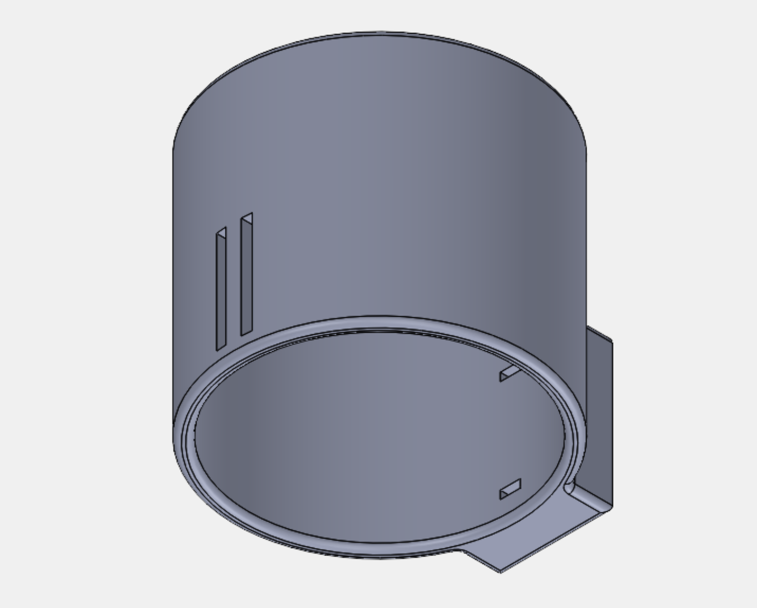


Figure 8.7: Ripstop Continuation Build CAD Model - Nozzle

The final design of the ABS Continuation will split the single manifold into two halves (left and right shells) which are assembled using snap fits. The details of the dimensions and locations of the snap fit features are out of the scope of this report, but as part of our build design we have modeled a simple cylinder (analogous to the tapered manifold) with a possible snap fit geometry as a proof of concept. This design will be 3D printed to demonstrate the feasibility of producing the ABS Continuation as two halves snapped together. Figure 8.8 shows the snap fit assembly, and Figures 8.9 and 8.10 show details of the male and female parts.

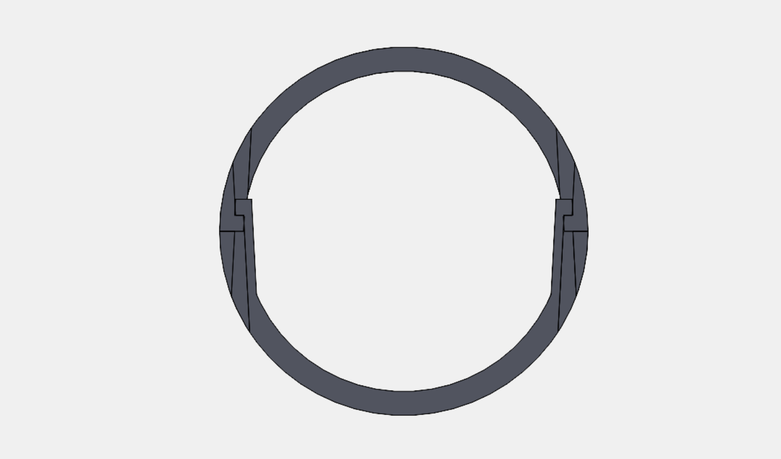


Figure 8.8: Snap Fit Test Build Assembly

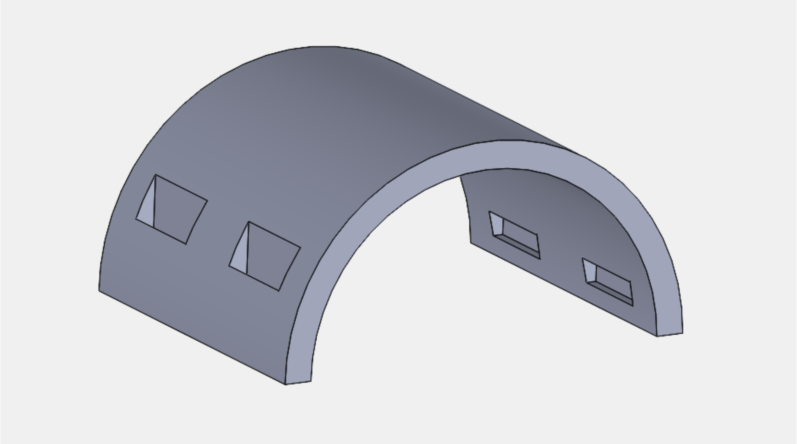


Figure 8.9: Snap Fit Test Build - Female

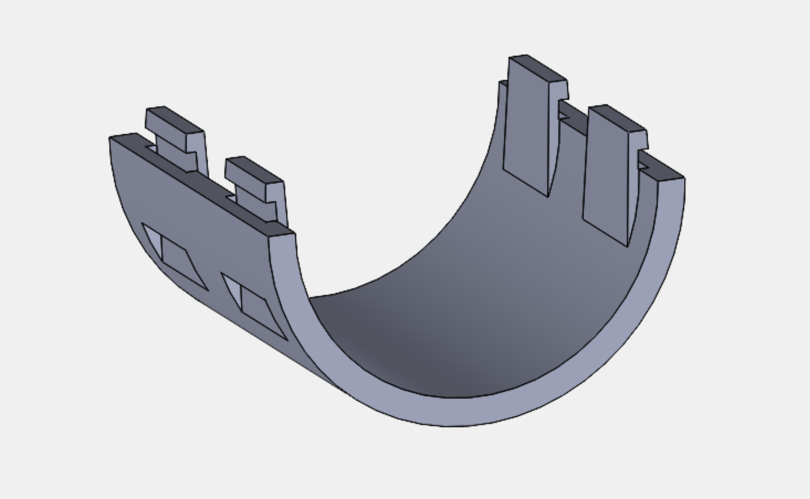


Figure 8.10: Snap Fit Test Build - Male

All parts shown above will be 3D printed in-house for the prototyping build phase. The Ripstop air tube which is shared by both designs will be sewn in-house. The rest of the parts will either be purchased off the shelf or have simple in-house manufacturing processes (for example, cutting nylon webbing to the correct length. Tables 8.1 and 8.2 list the parts for each design. Table 8.3 lists all materials which will be used to construct both designs.

Table 8.1: ABS Continuation Build - Parts

Part Name (qty)	**Material**	**Source**
Left Shell (1)	PLA	Made in-house
Right Shell (1)	PLA	Made in-house
Mirror (1)	Multiple	Provided by sponsor
Tongue (1)	Nylon	Made in-house
Air Tube (1)	Rip Stop (Nylon)	Made in-house
Hose clamp (2)	Stainless Steel	Provided by sponsor

Table 8.2: Ripstop Continuation Build - Parts

Part Name (qty)	**Material**	**Source**
Sled (1)	PLA	Made in-house
Nozzle (1)	PLA	Made in-house
Mirror (1)	Multiple	Provided by sponsor
Tongue (1)	Nylon	Made in-house
Air Tube (1)	Rip Stop (Nylon)	Made in-house
Hose Clamp (2)	Stainless Steel	Provided by sponsor

Table 8.3: Build Materials

Material	**Parts**	**Source**	**Manufacturer**	**Part Number**	**Cost**
PLA	Left Shell Right Shell Sled Nozzle	Purchased	Matter Hackers	M-SM7-3QYQ	$20.87
Nylon	Tongue	Purchased	Sailrite	100NYLWBK-FT	$0.30

Rip Stop (Nylon)	Air Tube	Provided by sponsor	—	—	—

Manufacturing each design will consist mainly of 3D printing, sewing, and gluing pieces together. The detailed process for manufacturing and assembling each version is outlined below:

ABS Continuation

1. 3D print the manifold
    a. Split manifold into smaller parts as needed to fit in printer build area
    b. Print each part in PLA
    c. Glue each 3D printed part together
2. Sew air tube
    a. Cut Ripstop into 1’x20’ rectangle
    b. Fold rectangle in half and sew along seam
    c. Fold over top and bottom, hem each (inlet and outlet)
3. Cut and install tongue
    a. Cut 1’ of nylon webbing
    b. Feed tongue through one slot from the inside of the outlet, cross over to the other slot along the top of the outlet, and feed tongue into the other slot from the outside.
    c. Pull tongue through slots so each side is even
4. Install air tube
    a. Place air tube around inlet
    b. Clamp air tube to inlet with hose clamp

Ripstop Continuation

5. 3D print sled and nozzle
    a. Split sled into smaller parts as needed to fit in printer build area
    b. Print each part in PLA
    c. Glue each 3D printed sled part together
6. Assemble sled and nozzle
    a. Align slots in sled and nozzle
    b. Feed zip tie in one slot from the outside and out the other
    c. Tighten zip tie
7. Sew air tube
    a. Cut Ripstop into 1’x20’ rectangle
    b. Fold rectangle in half and sew along seam
    c. Fold over top and bottom, hem each (inlet and outlet)
8. Cut and install tongue
    a. Cut 1’ of nylon webbing
    b. Feed tongue through one slot from the inside of the outlet, cross over to the other slot along the top of the outlet, and feed tongue into the other slot from the outside.
    c. Pull tongue through slots so each side is even
9. Install air tube
    a. Pull air tube through 4” diameter loop in sled

b. Place air tube around nozzle and fix with hose clamp
c. Fix air tube grommet to hole in sled

The build design for both versions is very similar to the final designs in appearance and function. However, since the manufacturing process used to produce the final design is central to this project, using 3D printing for the prototype build instead of injection molding requires some key modifications. First, due to the complexity of snap fit geometry required to form the ABS Continuation in two halves, it is not feasible to 3D print two halves in the same way it would be injection molded. This is due to the fact that snap fits are sensitive to which orientation the part is printed. Since snap fits would appear in multiple locations and orientations along the seam between the two halves, there is no orientation the model could be 3D printed where all snap fits would function properly. For this reason, the ABS Continuation will be prototyped in one piece for the purpose of testing its functionality.

However, the feasibility of snapping the two halves together can be confirmed using the snap fit geometry shown in Figures 8.8-8.10. 3D printing these parts in the correct orientation is possible, and testing the snap fit of these parts will confirm that the ABS Continuation can be injection molded in two parts.

Finally, a key difference between the build design and final design for both options is draft angle. The build design models have no draft angle to facilitate 3D printing without unnecessary overhangs or holes which would require support while printing. The final designs have between 0.5 and 3 degrees of draft angle to allow the part to be removed after injection molding.

Figures 8.11 shows the prototype build for the ABS Continuation, and Figure 8.12 shows the prototype build for the Ripstop Continuation.

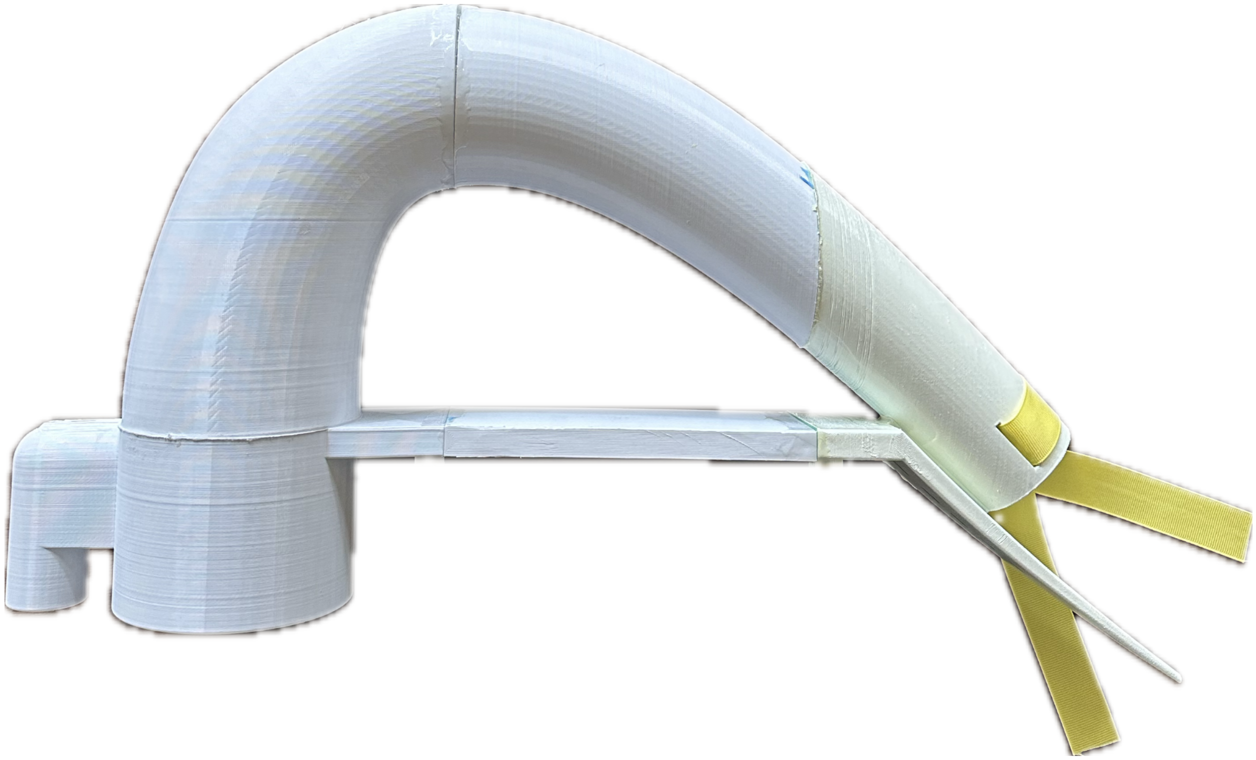


Figure 8.11: ABS Continuation Prototype Build

Figure 8.12: Ripstop Continuation Prototype Build

Final Design

As discussed above, the features of the final design for each option is very similar to the build design. Figure 8.13 shows the left shell of the ABS Continuation. Notably, there are sections of material removed from around the threaded hole and lower support structure. This is done to maintain a relatively consistent wall thickness throughout the part, which is critical for injection molding. Other material has been removed to eliminate undercuts which cannot be injection molded. The fact that in this version the manifold is assembled in two halves allows the mirror to be held captive by the tabs under the support structure, enclosed when the two halves meet. Draft angle has been added.

Figure 8.13: ABS Continuation Final Design CAD Model - Left Shell

The sled and nozzle of the Ripstop Continuation are also very similar to the build design. Draft angle has been added for injection molding. The hole in the 4” loop would require a side-pull mold, so it has been modified to be a notch on the lower side of the loop instead. 4 rectangular slots have been cut into the frame (seen in Figure 8.14) beneath the overhang of the snap fit features. This allows these features to be injection molded without the use of inserts. Figures 8.15-8.17 show details of the modified sled and nozzle.

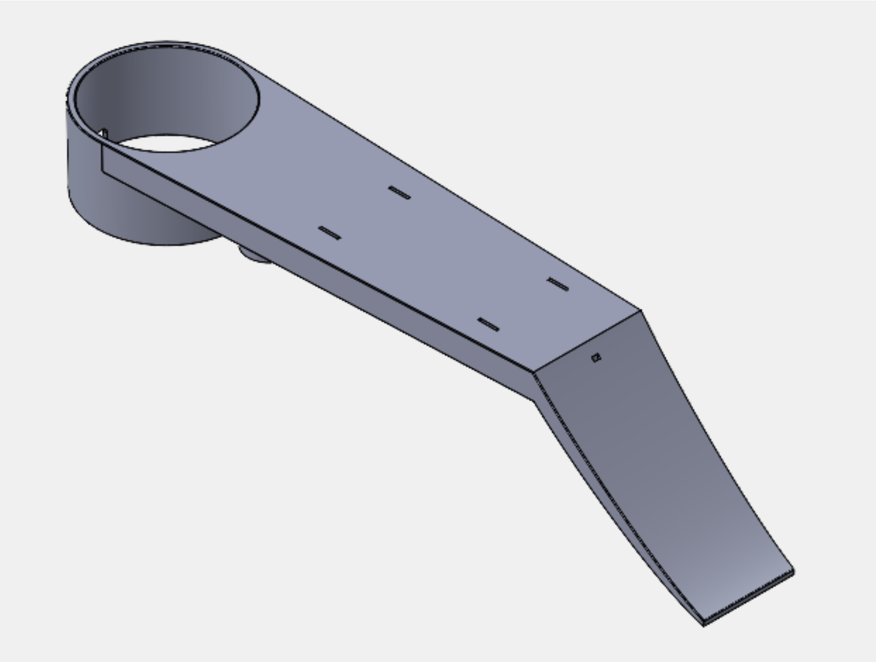


Figure 8.14: Ripstop Continuation Final Design CAD Model - Sled

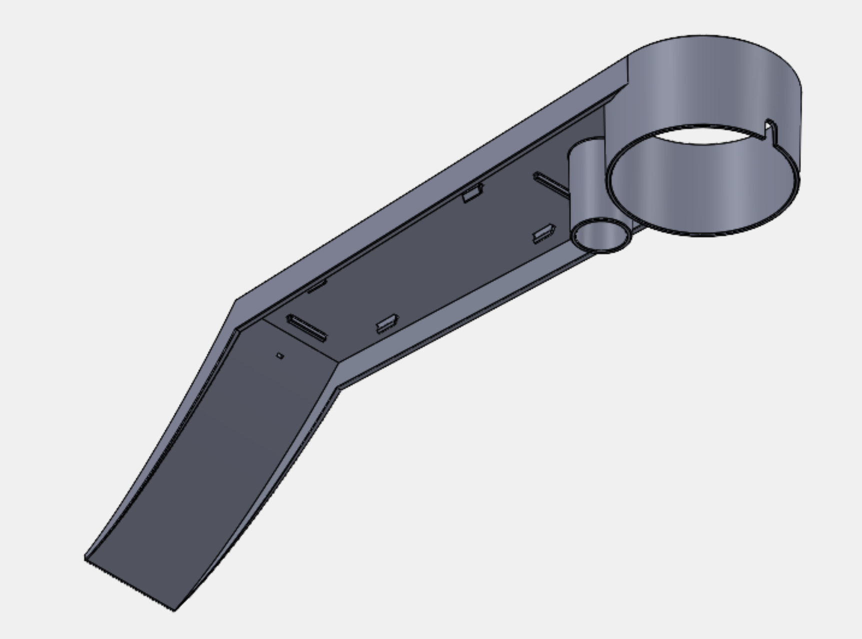


Figure 8.15: Ripstop Continuation Final Design CAD Model - Sled

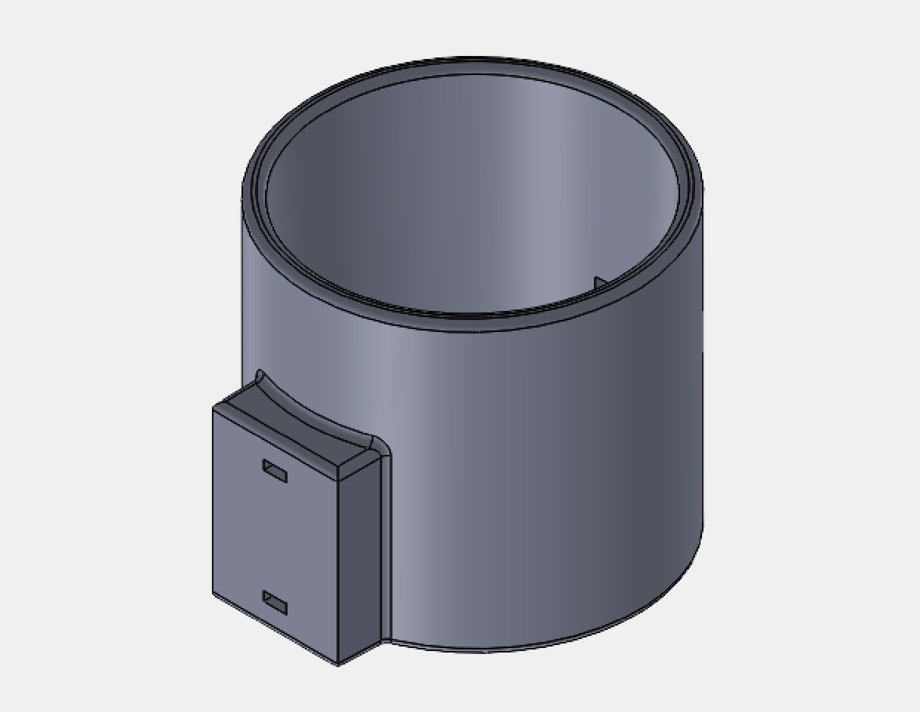


Figure 8.16: Ripstop Continuation Final Design CAD Model - Nozzle

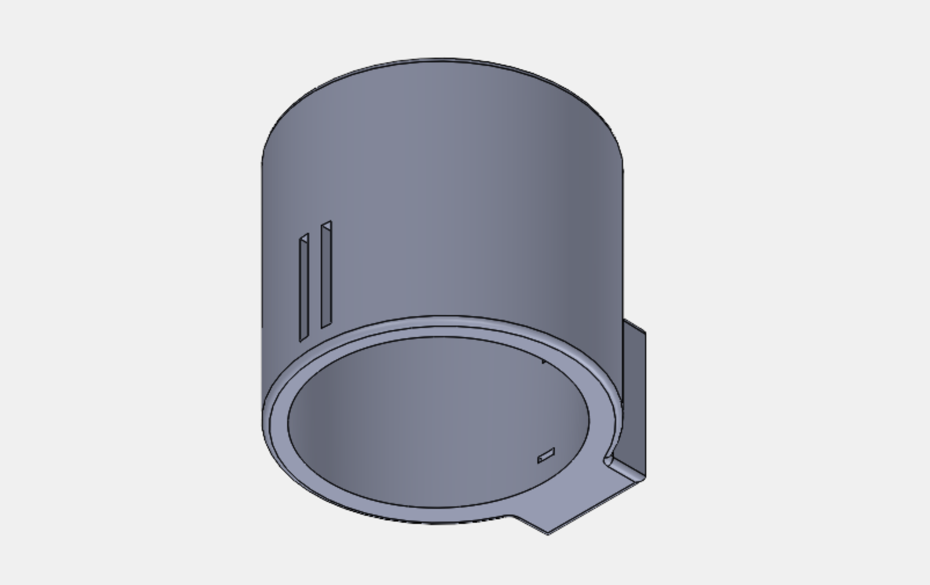


Figure 8.17: Ripstop Continuation Final Design CAD Model - Nozzle

Aligned with our goal to reduce assembly costs, the process to manufacture each version is straightforward, outlined below and ending where parts are delivered to the customer for assembly. Nearly all assembly is done by the customer for the ABS Continuation, while the Ripstop Continuation requires more involved manufacturing assembly due to the cable tie connection.

ABS Continuation

1. Injection Mold Half Shells
    a. Half shells are injection molded in ABS by Protolabs
2. Cut Tongue to Length
    a. Tongue is cut to length from a roll of nylon webbing with scissors using measuring jig
3. Sew Air Tube
    a. Air tube is sewn by Midwest Textiles from Ripstop nylon material
4. Pack Parts
    a. Left and right half shells, mirror (OTS), tongue, air tube, and hose clamp are packed for customer assembly

Ripstop Continuation

1. Injection Mold Sled and Nozzle
    a. Sled and nozzle are injection molded in ABS by Protolabs
2. Cut Tongue to Length
    a. Tongue is cut to length from a roll of nylon webbing with scissors using measuring jig
3. Sew Air Tube
    a. Air tube is sewn by Midwest Textiles from Ripstop nylon material
4. Assemble Main Body
    a. Insert cable tie into slots in sled and nozzle and tighten
    b. Cut excess material from cable tie
    c. Snap mirror into place

    d. Feed tongue through slots in nozzle and tighten
5. Pack Parts
    a. Main body, hose clamps, and air tube are packed for customer assembly

Tables 8.4 and 8.5 summarize the bills of materials for each version.

Table 8.4: ABS Continuation Final Design Bill of Materials

Part Name	**Custom/Off the Shelf**	**Manufacturer**	**Part Number**	**Cost**
Half Shell - Left	Custom - Injection Molded ABS	Protolabs	–	$14.97 (bulk, excluding tooling costs)
Half Shell - Right	Custom - Injection Molded ABS	Protolabs	–	$14.97 (bulk, excluding tooling costs)
Tongue	Off the Shelf	Sailrite	100NYLWBK-FT	$0.30
Mirror	Custom	Carryover from Original		$1.05
Hose Clamp	Off the Shelf	Carryover from Original		$1.21
Air tube	Custom - Ripstop	Midwest Textile		$10.80
			Total	$43.30

Table 8.5: Ripstop Continuation Final Design Bill of Materials

Part Name	**Custom/Off the Shelf**	**Manufacturer**	**Part Number**	**Cost**
Sled	Custom - Injection Molded ABS	Protolabs	–	$9.50 (based on original sled)
Nozzle	Custom - Injection Molded ABS	Protolabs	–	$4.39 (bulk, excluding tooling costs)
Tongue	Off the Shelf	Sailrite	100NYLWBK-FT	$0.30
Mirror	Custom	Carryover from Original		$1.05
2.5” Hose Clamp	Off the Shelf	Carryover from Original		$0.74
4.5” Hose Clamp	Off the Shelf	Carryover from Original		$1.21

Nylon Cable Tie	Off the Shelf	ULINE	S-5833	$0.10
Air tube	Custom - Ripstop	Midwest Textile		$10.80
			Total	$17.29

These designs have been shown to be feasible by our preliminary testing and experience with the original Gutter Viper. Neither design deviates significantly from the original product, and many dimensions like wall thickness (0.15”), overall size, material selection (ABS, stainless steel) have been proven out and copied directly. We chose to use ABS, stainless steel, and nylon because of their strength properties and weather resistance. The wall thickness was copied from the original and confirmed by guidelines from Protolabs. The use of zip ties to attach the sled and nozzle have proven effective when we modified the original product.

A key lesson learned comes from at first unsuccessfully designing snap-fit parts for injection molding. Initially, we expected that all snap fits used would require mold inserts, which greatly increase the cost of tooling, cost of production, and cycle time. However, upon consulting with an expert from Protolabs, we found that removing material beneath the overhanging part of snap fit geometry is a common way to produce snap fit features without inserts. As a result, we now have the expertise to design low cost snap fit geometry and have been able to reduce the cost of manufacturing even further.

SECTION 9: Verification and Validation Plans

Because the main focus of our project is to decrease the cost of the Gutter Viper, the main validation plan is the bill of materials comparing the original design to both of our final designs. Since the original gutter viper was produced and sold in 2018, we accounted for inflation since then using the Bureau of Labor Statistics CPI Inflation Calculator [24] to get the most accurate cost for analysis.

One of the hardest things to account for is the labor cost. Since we were not given a breakdown of labor cost in the original gutter viper, we had to come up with our own method for predicting these costs. This method consisted of replicating the timing of the labor for each of the different types of gutter vipers as mentioned in section 7 above. The results of this can be seen again in table 9.1 below.

Table 9.1. Summary of the labor assembly times of each type of gutter viper for each team member and their average

Team Member	**Original [s]**	**ABS Continuation [s]**	**Ripstop Continuation [s]**
Max	9:51	3:00	0:59
Holden	8:48	2:32	0:58
Jackie	9:19	2:15	0:53
Daniella	10:06	2:20	1:32

Average	**9:31**	**2:42**	**1:05**

Using these averages and the assumptions of a worker being paid $30/hour, adding on 35% to account for overhead, and 12% for shipping [26], we were able to get the following costs for the labor assembly. We were able to get these assumptions from discussing with an expert in the entrepreneurship field who had run his own company. While his company was different from assembly, he was able to give us the base numbers that he used.

Table 9.2. Summary of the labor assembly cost of each type of Gutter Viper.

Original	$6.84
ABS Continuation	$1.78
Rip Stop Continuation	$0.77

However, when we compared the labor cost of the original gutter viper to the assembly cost that we were given, there was a big discrepancy between them. Our calculations were off by a factor of 5.8. This could be due to many reasons; an important one being that there are no set labor calculations that every company abides by. Instead, each company internally addresses their need for profit, and charges based on that. Therefore, in order to compensate for the difference and make the cost numbers more accurate and representative of the real world, we decided to multiply the other values by 5.8. We also included a $2.00 picking part fee and added on 30% to account for profit of the company. This allowed us to get the final labor values seen below.

Table 9.3. Summary of the adjusted labor assembly cost of each type of Gutter Viper.

Original	$39.74
ABS Continuation	$10.32
Rip Stop Continuation	$4.47

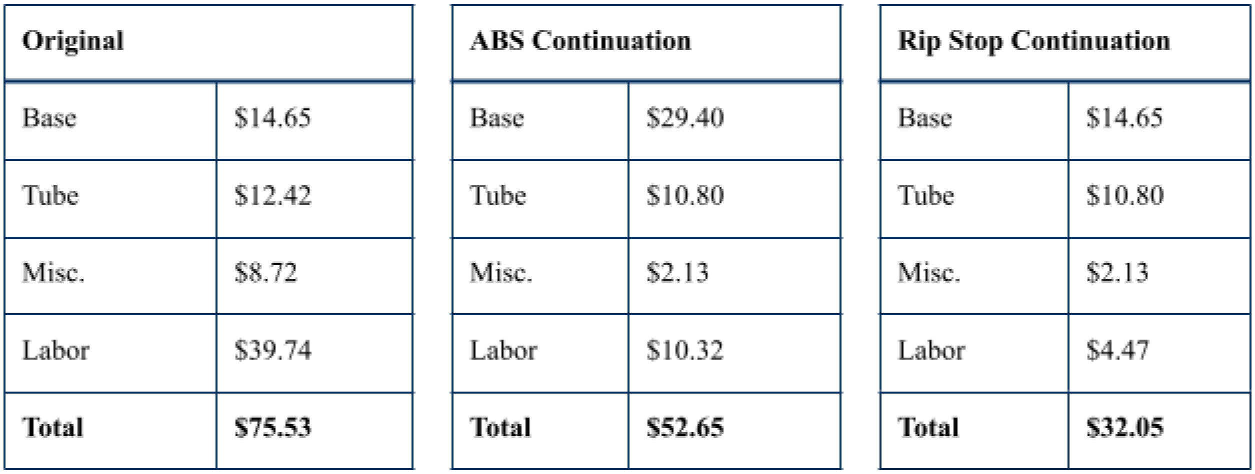
For the ripstop tubing, we were able to reach out to multiple vendors in order to receive quotes. The lowest quote was from Midwest Textile with $10.80 per tube.

There were certain items that we knew would cost the same from the original gutter viper to the new versions. These items were the mirror, nylon tongue, hose clamps, and shipping box. Therefore, we combined them into a miscellaneous category as they are not of much importance in the cost analysis. It is important to note that the original gutter viper also had cotter pins and threaded inserts. These items were also placed in the miscellaneous category.

The last assumption that we made was the cost of the body of the different versions. After DR3, we were able to get the cost of the body and the tooling cost. Our assumptions in DR3 were correct, so the base price stays the same. While we are not including tooling cost, we found it important to add as relevant information for making a final decision on which prototype to go with. The total tooling cost for the Ripstop Continuation is $37,995 and the total tooling cost for the ABS Continuation is $63,800.

A collection of these costs and final quotes is seen in the table below.

Table 9.4. Summary of the individual cost of each type of gutter viper and their total costs with the assumptions mentioned above.



Original	
Base	$14.65
Tube	$12.42
Misc.	$8.72
Labor	$39.74
Total	**$75.53**

ABS Continuation	
Base	$29.40
Tube	$10.80
Misc.	$2.13
Labor	$10.32
Total	**$52.65**

Rip Stop Continuation	
Base	$14.65
Tube	$10.80
Misc.	$2.13
Labor	$4.47
Total	**$32.05**

As seen above, we were able to reduce the price from the original by 30% for the ABS continuation and 58% for the rip stop continuation. While we did not hit our specification of $25, we have found this number to be extremely impressive with the reduction of labor cost. We also have concurred this with our sponsor who agrees that the lowest cost of $32.05 is good.

In addition to our cost validation, we decided to do a verification test to make sure that the product will function up to consumer standards. Since it was too cold to take our prototypes outside and use them in a real life scenario, we decided to make a mock gutter with fake leaves and test it inside.

Our mock gutter was made out of a paper shopping bag that had been cut to the shape and size of normal gutters. Our leaves were pieces of paper cut up into small squares, typically 1”by 1”. An image of this setup can be seen below.

Image 9.1 An image of our mock gutter set up made out of a paper shopping bag to represent the gutter and cut up pieces of paper to represent the leaves.

With our prototypes, we attached them to the leaf blower with the rip stop tubing and visually tested them to see if they worked. Our criteria for this was based on our past experience of using the original gutter viper. Since we had seen what the original is capable of doing, we knew how our devices were supposed to look like in action. Additionally, we could measure how many “leaves” or pieces of paper were left in the gutter after 15 seconds. This allowed us to quantify good cleaning.

After hooking up both devices and turning the leaf blower on, we were able to capture the results. Images of this can be seen below.

Images 9.2 - 9.4. Clips of the testing of the ripstop continuation prototype. Image 9.2 shows the gutter viper when the leaf blower had just been turned on. Image 9.3 shows the “leaves” being

blown out of the gutter. Image 9.4 shows the last couple “leaves” leaving the gutter and it being cleared of all debris.

Images 9.5 - 9.7. Clips of the testing of the ABScontinuation prototype. Image 9.5 shows the gutter viper when the leaf blower had just been turned on. Image 9.6 shows the “leaves” being blown out of the gutter. Image 9.7 shows the last couple “leaves” leaving the gutter and it being cleared of all debris.

For the ripstop continuation, after 15 seconds there was only one piece of paper left. For the ABS continuation, there were two pieces of paper left. This test proved that both of the devices cleaned exceptionally well. We did use the original as a control that had two pieces of paper after 15 seconds. Not only were we able to verify that the new versions of the Gutter Viper worked as well as the original, this was also a chance for us to test the tongue movement. With the new attachment method and placement of the tongue, we were unsure if it was going to act like the original with the cotter pin. This verification test allowed us to see the movement of the new tongues which again allowed us to virtually confirm that they work based on our previous experience with the gutter viper.

Overall, we have been able to validate and verify that our designs are appropriate solutions to the problem proposed to us at the beginning of the semester.

If we had been given more time, we would have wanted to conduct focus group discussions to see if users would actually buy either product. Because a big aspect of our designs surrounded aesthetics of our product, it would have been nice to see if consumers preferred one product over the other. Additionally, with a bigger budget, we would have bought an air velocity meter that could reach the speeds of the air flow coming out. This would have given us a more concrete analysis on how our designs compared to the original instead of visually testing them.

SECTION 10: Problem Analysis (aka “Threat Analysis”)

Through concept generation and the downselection process many of the specifications were automatically met due to them being simple design decisions. In order to make the Gutter Viper easy to assemble for the end user, all of the down-selected concepts have less than 3 connection points and use less than 3 tools. The easiest way to test the time constraint of assembly is to have a person with no prior knowledge of the Gutter Viper attempt to assemble a prototype. For durability, since injection molding the Gutter Viper was determined to be the best way to manufacture the inlet to outlet connection (scoop included) after our discussion with Professor Dan Cooper [22], the material will have to be plastic, ABS to be specific.

During that discussion, ABS was determined to be the best material for our application due to its strength and resilience to outdoor conditions (doesn't corrode). To test if the Gutter Viper can withstand a 20 ft drop, the obvious test will be to drop the prototype from 20 ft onto different materials (cement and grass).

Other specifications will be met and easily tested upon during the design phase of the down-selected concepts. To ensure that the new Gutter Viper will have a low weight, we can make considerations to limit the unnecessary material in the Solidworks model of the inlet to outlet connection. From there, we can use the density of ABS and the volume of the Solidworks model to determine the mass and confirm both of the models don't exceed 120% of the original Gutter Viper's mass. The other decoupled and down-selected concepts have a negligible impact on the weight and won't be considered in this stage unless the mass ends up being incredibly close to the specification. To ensure that the Gutter Viper is compact, the inlet to outlet continuation will be designed to fit into a 20" x 12" x 4" box as this concept will take up the majority of the room in the box. Other additions to the Gutter Viper problem are small and/or are flexible and will fit into the empty space of the box with the inlet to outlet connection. All simple dimensions can be measured in the Solidworks model. In order to make sure that the end user can see inside of the gutter while the Gutter Viper is in use, we will design for adding a 2" x 6" mirror on the underside of the inlet to outlet connection. The way the mirror will be attached is dependent on which of the two inlet to outlet connection concepts is chosen.

The new Gutter Viper will also be designed to be compatible with common yard tools and the standard gutter. To allow for a leaf blower diameter of up to 6", the leaf blower to inlet connection will be designed to have a 6.5" diameter. The extra half inch will allow for easy set up if the end user has a 6" diameter leaf blower and will not hurt the functionality. Along with this, in order to meet the requirement of being able to operate the Gutter Viper on the ground, the leaf blower to inlet connection will be at least 20 ft long. To fit the Gutter Viper in a standard gutter, its overall width has to be designed to be less than 5" wide. The compact requirement supersedes this requirement because the Gutter Viper needs to fit in a 4" tall box, so it will actually be designed to be less than 4" wide. The decoupled concepts for the pole connection point will be designed to fit a ¾ x 5 ACME painters stick, or alternatively a threaded pole attachment to a pole. This will be done by creating standard threads in a Solidworks model and can be tested once a physical prototype is created. The specification for effectively cleaning with a minimum of a 250 CFM leaf blower will be discussed later, but the compatibility and functionality of the Gutter Viper is dependent on this specification and it will create a lower bound for further testing.

The requirement of having low cost is a difficult specification to quantify at the beginning stages of this project. Through our downselection of all of the feature concepts, we used manufacturing and labor costs to attempt to evaluate concepts against each other. Our justification was mainly dependent upon the breakdown of the cost to manufacture and assemble one original Gutter Viper and developing ideas to decrease the cost in the especially expensive areas. Unfortunately, we don't have an actual cost breakdown of each down-selected concept, only general ideas about what will decrease cost. But in order to meet the specification of manufacturing and labor costs totalling up to under $25, we will have to talk to manufacturers and receive quotes from them. This will start with a Solidworks model of each of the inlet to outlet connections and some of the downselected feature concepts such as the tongue connection and the leaf blower to inlet connection. For these concepts, we have a good idea how to manufacture them, but the experts in the field will aid us in evaluating the designs based on manufacturability. Our downselected pole connection are essentially the same as the original Gutter Viper with some additions that do not need to be considered in the manufacturing process so the cost difference is known or negligible (adding a hose clamp to the box or telling the end user to buy the threaded pole attachment with a pin). The mirror attachment is dependent on the inlet to outlet connection concept and will be evaluated with those concepts.

Receiving a total cost from manufacturer(s) will hopefully not be the only communication about cost that we will have with them. Our plan is to attempt to have a conversation with the manufacturers about ways to reduce the cost via our design. For example the inlet to outlet connection concept, the ripstop continuation concept will still be injection molded with two pieces (nozzle and base) that will have to be connected. There are a few obvious ways to connect those, but which is the best way in terms of decreasing the labor cost? This is an example of one of the small choices that need to be made that are dependent on the manufacturer and their facility. The tongue connection and leaf blower to inlet connection will likely be evaluated in the same way if we can effectively communicate with the manufacturers. We can also evaluate cost reduction by getting quotes specifically from Protolabs, who supplied the injection molded parts of the original Gutter Viper. By comparing the original and new projected costs for parts from Protolabs, we can determine if our new design is really cheaper to produce.

Preliminary engineering analysis was performed using CFD to achieve two main goals. First, to determine if CFD would be useful in comparing the performance of a new design to the performance of the Gutter Viper. Second, given that CFD is useful to compare performance, to determine if duct shape has a significant impact on performance. This determination is useful because if the duct shape does not have a significant effect on performance, other limitations are lifted, such as the overall size of the duct and how other features are incorporated.

To achieve these goals in the absence of a new, detailed design, two models were created for use in CFD analysis. The first was a simplified model of the Gutter Viper in its current form. As shown in Figure 7.1, the basic shape and dimensions of the Gutter Viper are matched in the simplified model. Notably, the simplified model has a reduction in the cross sectional area near the inlet which matches a transition between parts in the Gutter Viper.

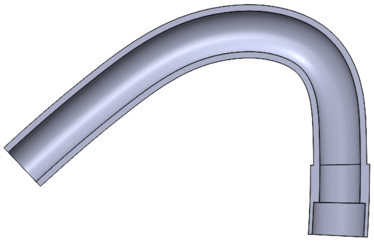


Figure 7.1: Simplified model of the Gutter Viper.

The second model (Figure 7.2) was designed to represent a “worst case” air duct. Many dimensions of the worst case model are kept the same as the simplified Gutter Viper, such as the arc length and inlet cross section/reduction. However, instead of having a gradual curve, the worst case model has an extremely short, abrupt 180 degree turn. This feature was used to represent the worst case because it would be expected to cause excessive turbulence and have negative effects on the air stream exiting the outlet.

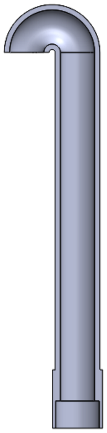


Figure 7.2: "Worst Case" model of an air duct with features similar to the Gutter Viper.

By using CFD to analyze these models, both goals mentioned above could be achieved. Since the Gutter Viper performs very well and the "worst case" model would be expected to perform poorly, if both models were given the same input and yielded the same or similar results, it could be determined that CFD would not be useful to compare performance. Then, if the results are significantly different, they can be interpreted to determine if the duct shape has a significant impact on performance.

CFD analysis was performed using ANSYS Fluent. The inputs to each model included a uniform velocity at the inlet which could be provided from a leaf blower with a flow rating of 250 CFM (minimum recommended for use with the Gutter Viper) and 0 gauge pressure at the outlet. Figures 7.3 and 7.4 show the velocity streamlines of each model. Figures 7.5 and 7.6 compare the pressure on the walls of each model.

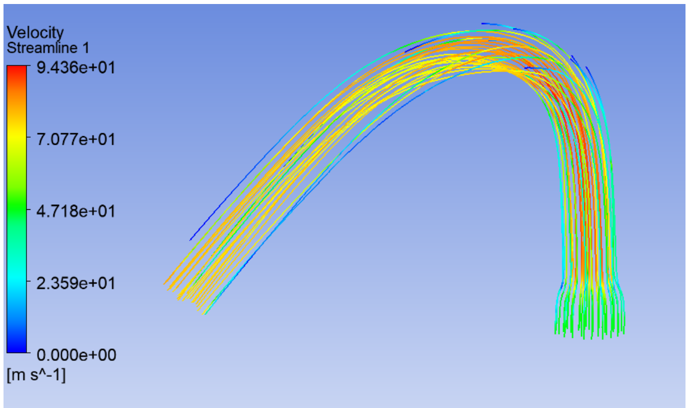


Figure 7.3: Velocity streamlines of the simplified Gutter Viper model.

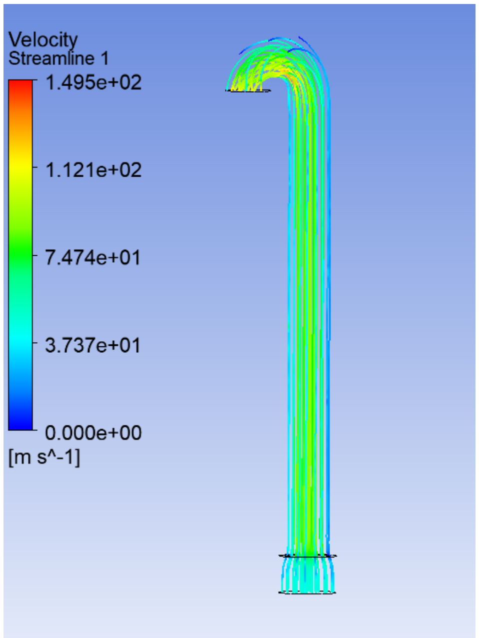


Figure 7.4: Velocity streamlines of the “Worst Case” model.

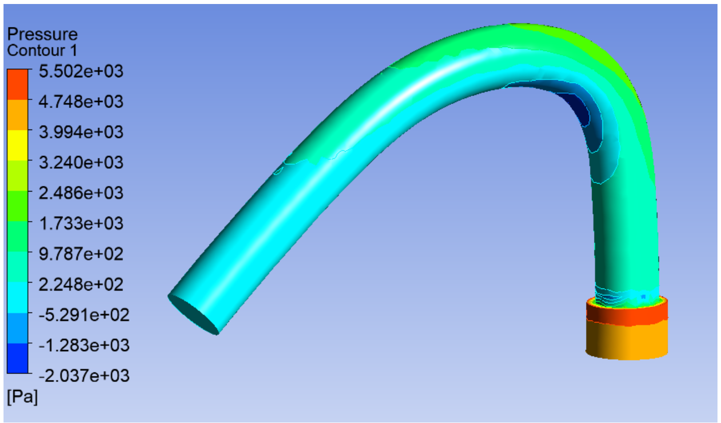


Figure 7.5: Wall pressure contour of the simplified Gutter Viper model.

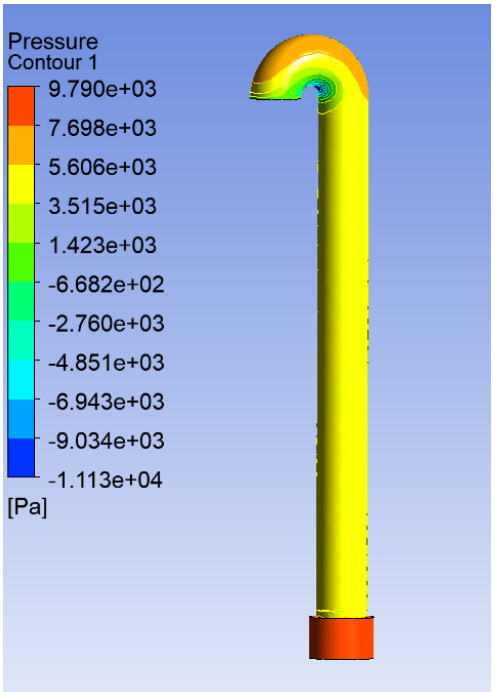


Figure 7.6: Wall pressure contour of the “Worst Case” model.

The above figures revealed useful information regarding the nature of the Gutter Viper. Most notable is that both high and low pressure zones are created around the bend of the air duct. High pressure at the top of the bend, and low (negative gauge pressure) at the bottom. Second, the streamlines of the worst case model reveal that the abrupt bend may not cause significant turbulence as expected.

The engineering specification of interest regarding the performance of the design specifies an exit air speed which is at least 90% of that from the original Gutter Viper. To identify the exit air speed of each model, they were oriented so that the outlet was perpendicular to the Y-axis and the average Y-velocity at the outlet was calculated using an area-weighted average. The results are given in Table 7.1, and the velocity contours of each model are given in Figure 7.7 and Figure 7.8.

Table 7.1: Area-Weighted Average Y Velocity.

	Simplified Gutter Viper Model	**Worst Case Model**
Area-Weighted Average Y Velocity (m/s)	76.00	76.03

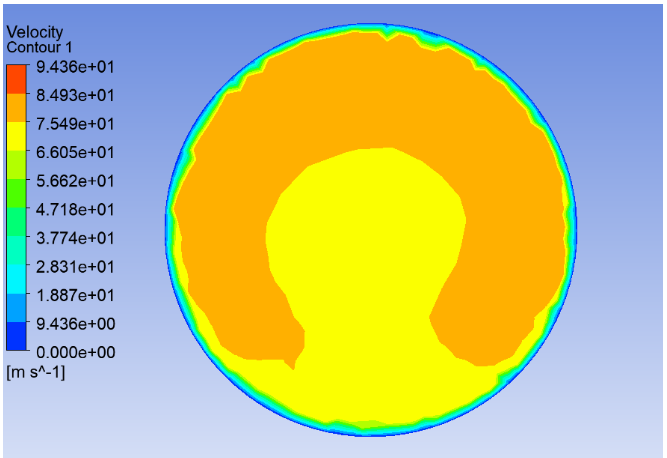


Figure 7.7: Outlet cross section velocity contour (Gutter Viper).

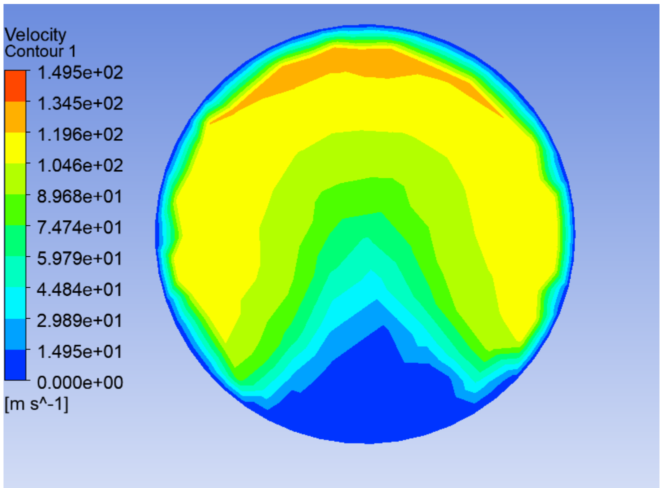


Figure 7.8: Outlet cross section velocity contour (Worst Case).

The above figures also show surprising results. Despite the worst case model having such an abrupt bend, the average velocity at the outlet (specifically, velocity in the direction it is aimed) is not significantly lower than that of the Gutter Viper. In fact, it is slightly higher, though given there is some uncertainty in the calculation, it is effectively the same. Also, it can be seen that although the average velocity is the same, the velocity at the outlet of the Gutter Viper is much more consistent than the worst case model, which has very low speeds at the bottom of the outlet and extremely high speeds at the top. The CFD model was also used to look at mass flux at the outlet. By definition, the average mass flux at the outlet should be exactly the same between the two models. However, as shown in Figures 7.9 and 7.10, the distribution of mass flux is very different.

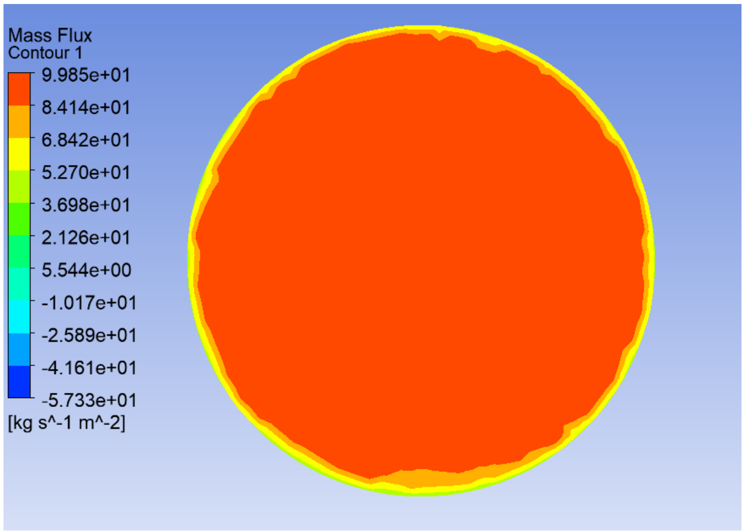


Figure 7.9: Outlet cross section mass flux contour (Gutter Viper).

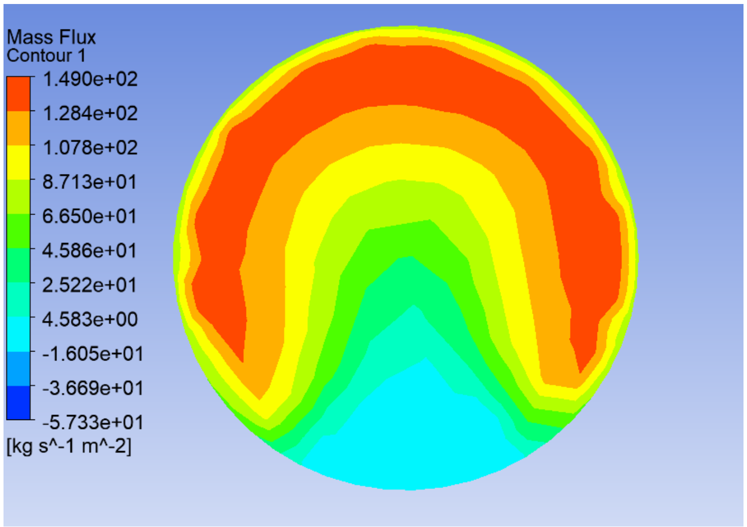


Figure 7.10: Outlet cross section mass flux contour (Worst Case).

As shown in Figure 7.9, the mass flux at the outlet of the Gutter Viper is extremely consistent. Compare this with Figure 7.10, which shows that the mass flux of the worst case model is extremely varied, including a negative mass flux at the bottom of the outlet. This means that air is not being pushed out, but pulled in at the bottom of the outlet. This is not desirable because it means that the air coming out of the outlet may not reach leaves which are directly in front of the outlet.

Several conclusions can be drawn from this preliminary analysis. First, it can be concluded that CFD analysis is useful in assessing possible designs. Even if only qualitatively, it can show unexpected behavior such as the location of high and low pressure zones. It can also bring up new ideas, such as possibly using an unevenly distributed mass flux as an intentional feature. Second, it can be determined that the duct shape does affect performance, but it is not clear just by looking at exit velocity like original engineering specifications call for. The consistency of mass flux is a better indicator of performance which can be measured by CFD, which has led us to modify the performance specifications as discussed in Section 4.

Since the end of DR #2, many decisions have been made and therefore the range of problems that we can come across in the future has significantly reduced. Our next steps are to 3D print the models and do more verification testing on the prototypes that are as similar to the final design as possible. Since we have already completed verification testing on simpler prototypes and they were successful, it is unlikely that these tests will not work. But in case we discover something detrimental in one of the designs, we always have the other design to fall back on.

Other than that, there is not much more work to be done on our end. We plan to display the options to Professor Ashton Miller and have him choose the final product. Once this final design is chosen, although out of scope for our part in the project, some problems still may arise. Professor Ashton Miller may run into a problem of tooling wear in the case that he does not decide to go with Protolabs for the injection molding (they replace the tools for free if necessary). Tooling wear can affect the material strength of the end product which can ultimately lead to quality issues. Some other potential issues that Professor Ashton Miller could potentially run into in the future are problems within the supply chain, rising material costs due to inflation, and rising labor costs. Unfortunately these are all out of scope for us and are highly unpredictable, Professor Ashton Miller will have to evaluate the best move if these problems arise.

SECTION 11: Discussion

Throughout this semester, our problem definition shifted when we decided to continue on with the original patent of the Gutter Viper. It went from “cleaning high gutters from the ground” to redesigning the original Gutter Viper for cheaper mass manufacturing. The original Gutter Viper successfully meets all of the points in the first problem statement, so it was an easy decision for us to make to keep the patent (and it was nice to honor the original ideas of Professor Ashton Miller). If we could do it again, I think that we would have searched for alternate ideas to solve the original problem statement and essentially scrap the concept of the original Gutter Viper. This would have opened up a lot of doors for us to be more creative with the design and its functionality. Although, with our original brainstorming methods, none of the ideas seemed very feasible to make at a low cost, but with some work I’m sure a few of them could have worked out.

The knowledge of the fact that the original Gutter Viper works very well and the verification testing gave us a lot of confidence in our new designs. We know that either of the designs work very well, so the big issue is still cost. Unfortunately, we did not meet this requirement, so if we could go back, we would find ways to bring the cost down more. The biggest costs for both of the designs was the injection molding cost and the rip stop tube cost. Fortunately, we were able to get the labor costs down a significant amount, so we would need to focus on those other two aspects. For the injection molding costs, ideally we would talk to Proto Labs or potentially some new suppliers who could have cheaper costs. Talking to an expert or getting a detailed cost breakdown of the specific parts of the injection mold would help us find ways to get the individual cost down. We do know that decreasing the size of the injection molds will significantly decrease the cost because the injection molder would need to apply less pressure and heat for the smaller parts. This can specifically be done on the ABS continuation, we think that that version could be downsized quite a bit without any functionality issues (we would need to create a prototype and test it before we know for sure). For both the rip stop tube and the injection molded parts, it would be nice to negotiate and shop around a good bit more between suppliers. If we were to be the ones to bring the Gutter Viper to mass production, that would be our next steps and something that we would take special consideration for because it can significantly change the final result (cost and quality).

One of our biggest challenges throughout the project was finding ways to reduce cost without fully knowing how much they were going to cost in the end. Since a lot of the cost relied on the injection molding and we had to have fully fleshed out designs to send to Protolabs, we did not have the time or experience to design for cost reduction. We essentially had to make educated guesses for the CAD model and control the costs where we could. So some potentially risky choices needed to be made with the design. Ideally, we would have liked to design and iterate on the design as we got cost information back. In the end, the choices that we made were good and did decrease the cost, but the risk is in not knowing if we could do better. Depending on the price point that Professor Ashton Miller wants to set the new Gutter Viper at, not meeting our cost goals could negatively impact the end users by having to pay more for it.

SECTION 12: Problem Domain Analysis and Reflection

Many of our requirements come directly from using the original Gutter Viper as a benchmark for many qualities. This is beneficial because we can use the original to compare to see if our new design has improved. With this comes the downside that a lot of the specifications can be subjective and hard to test. The specification “cleans just as well as the original Gutter Viper” is a challenge to truly test because of the vast variety of testing conditions, the subjective nature of the claim, and the potential for us to not test the prototype at all because of the seasons changing.

Potential solutions to this include computational testing with finite element analysis and computational fluid dynamics. With Finite Element Analysis (FEA), a model of the original Gutter Viper can be directly compared to the new design when put under stress from simulated forces like using the scoop on wet leaves. This can take into account the material and the specific geometry [17] of both models to create an accurate comparison for the forces each can handle. It can even help us during our design process by predicting where much of the stress will occur and then our group can iterate off of that information. With Computational Fluid Dynamics (CFD), a similar comparison can take place, but this time with the fluid flow of the simulated air from a leaf blower. Both models can be created and tested in similar conditions to see if their fluid outlet flow is the same. Once again, this information will also be helpful in the design process so we know what to improve. CFD is new to most of our members of our team, so it will be a challenge to learn this new skill. To start, we plan to review sources such as *Think Before You Compute* by E.J Hinch [16].

Due to this, there aren’t any standards that apply to gutter cleaning, but there are standards around manufacturing of plastics. Looking into these standards like from JIS B 6701:1992, Dimensions Relating To Molds For Plastics Injection Molding Machines [21], will not only help us understand the design of the original Gutter Viper, but also include injection molding fundamentals into the very beginnings of our design.

A large gap in our knowledge for the specifications comes from the manufacturing and labor costs. These are of course highly dependent on how we decide to design and manufacture the product, something that we are currently unsure of. To tackle these beginning stages of the design process, we intend on talking to Professor Dan Cooper, an expert in manufacturing. In these conversations, we will emphasize the need for cheap manufacturing while keeping in mind the structural integrity of the product. With that knowledge, the next step is to do deeper research into the intended plastic manufacturing processes with special considerations for the shapes possible, material strength, and a good estimation on the cost. Some sources for this information include *Injection Molding: Process, Design, and Applications* by Phoebe H. Kauffer [9] or *Blow Molding Design Guide* by Norman C. Lee [10].

Using the design principles from those sources for the plastic components of the Gutter Viper, and confirming that the design is working as intended from FEA and CFD analysis, eventually we will have an ideal design. Ideally, a 3D model of the design can be sent to manufacturers that can not only provide hard pricing but also alterations to the design so that it can be produced well according to their standards and equipment.

The other aspect of the manufacturing and cost we need to consider is the fabric duct. We do know that a large portion of the labor costs are due to the sewing of the fabric on the duct so finding an alternative is a high priority. This is a unique problem because there aren't a lot of other products like the fabric tube due to its weatherproof fabric and overall shape. Although, we can use other products with seams as an example, like heat sealing (we plan on looking into sources such as *Automation in Garment Manufacturing* by Rajkishore Nayak and Rajiv Padhye[13] and *Heat Sealing in Packaging: Materials and Process Considerations* by Abdellah Ajji, et. al[1]).

From the end of DR#1 to now, a lot of the project's goals have been cleared up due to research and concept generation. Since we have decided that the Gutter Viper is a good solution to the problem and to stick with the original utility patent, our main deliverable will be a variety of evidence that our new design meets all of the requirements. To do this we will 3D print a prototype that can be tested upon based on the specifications. One of the main drivers of this project is the cost, which as far as we know now will likely be difficult to get hard numbers on. The injection molded parts are not the issue as manufacturers should be able to give us a cost per part, the labor is where a lot of the issues lie. We could talk to manufacturers and get an estimate of the cost for labor (if they allow us to inquire about cost), but by the end of the semester we will not have an injection mold for the new model, so testing the time it takes to manufacture it will be difficult to do. To remedy this, since we have the labor cost breakdown of the original Gutter Viper, we can simulate assembling the Gutter Viper and track the time it takes. From there, we can do the same thing for assembling the new Gutter Viper and compare time and therefore cost to the original. We are currently inquiring with Professor Ashton Miller to see if he has any more information about the cost breakdown of the labor that can aid us in estimating the new labor cost.

The 3D printed prototype may also not be as simple as we would like. The prototype needs to be 3D printed because the injection mold actually being created for the new Gutter Viper is out of the scope of this project. Due to this, we are limited in the materials that we can use to create the prototype and how we can create it. Unfortunately, 3D printing and injection molding are very different processes and lead to very different results. For example, the layers within the 3D print create many weak points that an injection mold will not have, and the material will be different from ABS. Due to this, the drop test may not be accurate, but since the 3D print will be weaker, we can conclude that if it doesn't break in a drop test, the injection molded Gutter Viper will be sufficient. If it does not pass the drop test, we can evaluate where it failed and reinforce those areas (the weak areas in the 3D print should be the same weak points in the injection mold).

The threads for the pole connection within the prototype will be very difficult to 3D print, but the downselected concepts for the pole connection are based on solutions that do not involve a different injection mold. The original Gutter Viper's threads work so it is a proof of concept of our pole connection ideas. The snap fit for the mirror will also be quite difficult to 3D print. To remedy this, a prototype of just this function will be created to show that the snap fits do in fact work, this can potentially be by 3D printing the snap fits and gluing them to a surface. Snapping the mirror onto the surface will be a valid proof of concept that the snap fit works.

For the inlet to outlet connection concept, the manufacturers will only be able to provide us information about the price and feasibility for manufacturing. So their feedback and the model CFD will be helpful for meeting requirements, but it's hard to know if in real life it will be functional. We are especially concerned with the ripstop continuation concept for the inlet to outlet connection. There is a potential for the ripstop to kink at the bend at the very top point of the Gutter Viper since it is flexible fabric. To ensure that it is functional, we plan to create a variety of tube shapes out of ripstop and test them in a set up similar to the ripstop continuation concept. We will do this by measuring the distance between the inlet and outlet (and angle of outlet) of the original Gutter Viper and simulating those positions with cardboard and rigid rings to act as the inlet and outlet. Then we will simulate use by attaching a leaf blower to the inlet and seeing if it kinks. Ideally, a rip stop tube made out of a simple rectangle will work just fine and not kink since it is the easiest to manufacture. If that does not work we will iterate the tube design to include tapering, shape, and potentially other methods for reinforcing the tube. If none of these iterations work then we can move onto our other inlet to outlet design: the ABS continuation.

Currently, many of our information gaps come from not knowing exactly what information we will receive from the manufacturing companies that we reach out to. The more information the better for iteration, and a back and forth relationship between the manufacturers and us would be ideal, but it is unknown if we will be able to do that. There's not much we can do about this now, but we will adjust as we gather information. Professor Ashton Miller has been in the exact same position as us before, so we will always consider him as a good source of information if any issues arise in this stage.

Updated Reflection Since DR#3

Prompt #1
A factor that has always been very important to our project is the public health and safety, or more specifically, the end users of the Gutter Viper. Keeping homeowners and landscapers from climbing on roofs is the core motivation for this project. The Gutter Viper can help people stay off of their roofs globally if Professor Aston Miller decides to sell it in other countries, if not, then it will not have much impact on a global scale. Socially, the Gutter Viper will likely not have much impact as it is a product meant for one person to use, but maybe a neighbor will ask the end user about it. Economically, the Gutter Viper might contribute to some landscapers losing some business over time since the Gutter Viper is a significantly cheaper product than paying for their services. The design can also bring some business to

all of the companies that go into constructing the Gutter Viper. At the start of the semester, we used a stakeholder map to analyze who our design would be affecting and how much we were willing to consider that effect in our design. Some of the major stakeholders were Professor Ashton Miller and the end user. We also did some life cycle analysis on the final product to ensure that we were reducing the environmental cost that comes with production and disposal.

Prompt #2

Culture, privilege and identity did not have a significant impact on how we worked with each other because we all have very similar backgrounds. I would argue that we are a very privileged group, so this may have had an impact on how we compared to other groups, but not necessarily with each other. Our differences were really highlighted with the skills that we had as well as the time on that specific week. I think that we all contributed when we had the skills and time to do so. We readily recognized when one group member was having a busy week and picked up slack when necessary.

A similar statement can be said for our relationship with our sponsor. There could have been potential for a power difference between Professor Ashton Miller and us because he originally designed the product and knew significantly more about it. I could understand wanting to direct us in a specific way to benefit him but he didn't do that. He gave us the creative freedom to do what we wanted while giving us the knowledge when we asked. We were very appreciative of this relationship because we think that it resulted in one of the best possible final designs with the time that we had.

Prompt #3

Once again, since all of our team members came from very similar backgrounds, there was not much of a power imbalance between members of our group. The times that there were some, it was because one member of the group had more knowledge about a particular topic or skill, so their word often had a stronger meaning than other members of the group. The same can be said about the power dynamics with Professor Ashton Miller, although he let us have our creative freedom, because he had gone through a very similar situation as us, his words had a lot of value to us. We knew his experience was invaluable for us.

I think that in general, our group was very welcoming to new ideas, especially ones that a particular member of the group felt strongly about. If there was enough work done before the idea was brought up to justify the idea, we were all very open to pursuing that idea. We also often took into consideration the team members' experience in previous jobs or projects. The more work a certain team member had done in a specific area, the more we valued their opinion on that specific topic. This could've been where some power imbalances originated from because some opportunities were presented to some of us in the past and not others.

Prompt #4

A lot of our ethical dilemmas were caused by the amount of time that we had to create the final designs and all of our busy schedules. Since the original Gutter Viper works well and is safe, we knew that we just had to uphold those same standards in our final design, which we did complete. But, there were some hard choices that we had to make with the time frame that we had for the new designs because of time constraints. Choices needed to be made quick and efficiently so we could move along with the class schedule and fit into our own schedule. If we had more time, we could have had much more fleshed out designs to the point where we felt each and every detail of the design was perfect. Although, this is probably part of the point of ME450, to find the best solution to the problem under intense time constraints to really put each student under some sort of pressure. If that is the case, I think that we did the best that we could.

With our own personal ethics, we would have liked to have taken our time on every detail to ensure that this product is perfect (not necessarily including safety, throughout this project we have taken safety as our top priority so it is already as safe as it can be). This is quite different from the University of Michigan's ethical priorities or even a potential future employer, because they are often working on a strict timeline, and perfect doesn't always make the most money.

If the product were to enter the market place, some ethical dilemmas could arise in the companies that go onto manufacture and sell it. Our hope is that Professor Ashton Miller chooses manufacturing and assembly companies that have documented and well thought out labor practices, to ensure that the creation of this product is going to benefit laborers instead of hurt them. The same can be said for the company who originally sold the Gutter Viper, Amazon. They have a laundry list of unethical labor practices for people who work in their fulfillment centers and delivery drivers. The dilemma now is determining whose responsibility it is for those labor practices and whether the costs outweigh the benefits of selling products on their platform.

SECTION 13: Recommendations

Based on our engineering and cost analysis, we recommend that our sponsor, Professor Ashton-Miller, pursue the ripstop continuation design for mass manufacturing. We believe that the ripstop continuation design is better than the original design because it is able to maintain product functionality of effectively cleaning leaves from gutters, as proven in our validation testing above. Moreover, we believe the ripstop continuation design is advantageous over the abs continuation design because it is much cheaper to produce; cheaper tooling, less abs material costs, and less assembly required that can be offset to the end user. Ultimately, we believe that the ripstop continuation design can launch at a competitive retail price for customers while maintaining the ability of the original design to effectively clean gutters.

Furthermore, we recommend additional investigation into design changes that may yield cost savings while maintaining original product performance. Specifically, we suggest performing further fluids analysis to find the most optimal airflow tube diameter, and thus pressure drop, between the outlet of the leaf blower to the outlet of the Gutter Viper to maximize airflow and minimize efficiency losses. While we did perform CFD analysis to find the most optimal tool inlet-outlet shape/configuration, we recognize optimizing the airtube geometry itself may pose beneficial gains in the ability to effectively clean leaves and potentially decrease material costs.

In addition to tube geometry, we further suggest investigating different assembly methods or airtube material that may reduce costs. While we chose to simplify the stitch pattern of the airtube, we recognize that an assembly cost four times the material cost of the ripstop nylon material is quite expensive.

Therefore, we recommend looking into ways to reduce this assembly cost, specifically via heat welded seams or selecting a different material. For example, while it may not be as durable as the ripstop nylon, we looked into poly tubing as a low cost plastic air tube that would eliminate any associated assembly costs. Significantly reducing or eliminating the air tube assembly costs would decrease the overall part cost by as much as 34%, and would permit the ripstop continuation design to reach the intended cost target of less than $25.

Moreover, we recognize beyond the scope of this project from a business point of view to maximize profits, it would be in the best interest of our sponsor to communicate to consumers the cost savings over time of the Gutter Viper, in addition to how to properly use the tool. Consumer acquisition is extremely important in creating a profitable product, and therefore we recommend advertising specific to consumers the advantages in cost savings overtime of using a tool like the Gutter Viper vs more expensive alternatives, such as gutter guards or gutter cleaning services. Consequently, customers will only use the product as intended if there is good supplemental instruction informing them of how to properly use the tool. Therefore, we recommend that the instructional pamphlet be reformed to include all of the tips and tricks on how to not only assemble the Gutter Viper, but how to operate it efficiently as well. For example, during our testing, Professor Ashton-Miller gave us a tip to pull down on “latch” the tool onto the gutter itself when first starting up the leaf blower to minimize the initial kick back. This tip would be extremely useful to customers upon first using the product, as in nowhere explained in the original instructional aide.

As mentioned in the discussion section, we recognize that alternative methods may hold viable methods to cleaning leaves from the ground at a lower cost than our recommended design solution. Therefore, we suggest to have the utmost confidence in this product, to go back to the drawing board and verify that alternative solutions in the design space do not hold the same effectiveness at this intended price point. We think that to minimize the cost as much as possible, investigating mechanically only driven methods to remove leaves from gutters may pose feasible designs to clean gutters from the ground. Granted, we recognize that these solutions may come at the expense of time saving efficiencies and ease of use.

SECTION 14: Conclusion

In summary, we are focused on reducing the cost of the Gutter Viper, a tool that provides homeowners a safe solution in avoiding the use of ladders to clean their gutters. We began tackling this project by doing market research about the current product through customer reviews and benchmarking by looking at competitors. Next, we identified relevant stakeholders, most specifically our sponsor Professor Ashton-Miller and homeowners, in which we will consult with on major decisions made during the design making process. Considering these stakeholder needs, we developed a working set of requirements and testable engineering specifications that define the characteristics of the new Guter Viper product. Since DR1, we have completed our concept generation and downselection leaving us with 2 final ideas: continuation of ripstop to replace the tube connection or two ABS symmetrical halves that are glued together to become one. We have also used CDF to help determine our worst case scenarios and refine specifications. Since DR2, through research and evaluation we chose the best of the down-selected concepts for our final design, except for the inlet to outlet connection. For that concept, we decided to fully evaluate both options by pursuing both routes. Prototypes were created and tested upon to ensure that both concepts work. Then two CAD models were created and sent to Protolabs. With the cost estimation from Proto Labs and labor time testing, a detailed cost breakdown for each concept was created. After DR3, we completed both prototypes and presented them in the design expo. Our sponsor came to the expo and was impressed by our results. We have done the validation and verification testing by making a makeshift gutter and using paper to mimic leaves. We tested both of the prototypes, which passed. We will now combine all of the knowledge we have learned over the course of this semester and hand it over to our sponsor, Professor Ashton Miller, where he can choose which design he will further pursue for mass production.

SECTION 15: Acknowledgements

Our sponsor Professor James Ashton-Miller and our mentor/"fifth teammate" Dr. Jonathan Luntz.

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SECTION 17: Bios

Daniella Chait

I was born and raised in Seal Beach, California where growing up, I would spend hours with my dad building different K'Nex kits from roller coasters to ferris wheels. This is where I developed my love for creation and design. In the Summer of 2023, I had the privilege of working as a Manufacturing Engineer Intern at GE Aerospace. My work revolved around the T700 helicopter engine, affording me invaluable experience in the realm of aerospace and manufacturing. After I graduate with a BSE in Mechanical Engineering with a concentration in manufacturing, I will return to GE Aerospace in their Operations Management Leadership Program (OMLP). Within the program, I will rotate through three different positions across the

company ranging from Operations Supervisor to Process Engineer. Outside of engineering, I work as an Instructional Aid for ENTR 500 - An Introduction to Innovation: Tools for Career Success. Additionally, I tutor local Michigan high school students in math and physics. Outside of my professional pursuits, I enjoy cooking, reading, art, and traveling.

Max Mancini

I am a Michigander born and raised from Clinton Township. In all honesty, I was referred to mechanical engineering by my high school math teacher because I was good at math. But I am glad I chose it as my major because I enjoy solving a variety of complex problems. Growing up I really enjoyed building legos and helping my dad work on random projects around the house. This past summer I had the opportunity to intern for bp at the oil refinery located in Whiting, Indiana. My projects included designing a chemical injection system, ordering new tubes for heat exchangers, and adding a relief valve to piping. I really enjoyed my time at bp, but I think after graduating this December I will be looking for a role more involved in the design process. As of now I have been applying to companies in the automotive and defense industries. Apart from course work, I was previously involved in the Solar Car team designing the windowed fairings for the car we are racing in Australia this October. I enjoy following Michigan sports, specifically football and volleyball. I spend my free time exercising, I usually like to run or cycle, and have recently started doing calisthenics.

Jacqueline Henrietta

I grew up not too far from Ann Arbor in a small town south of Detroit called Flat Rock. My family didn't have a ton of money growing up so I had to problem solve with what I had, which I truly believe helped me build the skills to be an engineer today. I taught myself how to sew, I always helped with household projects, and I learned how to budget my money and time. During high school, I was pretty good at math and science, and I loved working with my hands and creating things. Mechanical engineering seemed like the obvious choice with that in my mind so very little research went into

my decision. Freshman year, there were some surprises along the way, but I'm stubborn and always up for a challenge so I stuck with it and I'm glad I did. I love the program, but I am also happy to be done with it. After graduating, I will be working for a mechanical subcontractor where I will be a project manager designing and managing process piping and HVAC projects. Deciding to work in construction was a bit of a surprising career choice, but I'm happy to be following in the footsteps of many of my family members.

Holden Collins

I grew up in Saline, Michigan, where I participated in Marching Band, Track & Field, and First Robotics. My passion for engineering started in middle school when I took a 3-day course in blacksmithing at Tillers International. Leveraging the knowledge and skills I gained in that short time, when I came back home I built my own forge and anvil to get started in my garage. Since then, I've always been driven to develop new skills to make things. This has led me to machining, metal casting, welding, CAD, 3D printing, and more. When I started driving at 16, I added automotive work to my set of skills. I began to incrementally mod a 2006 Mustang GT I bought with my father when I was 17, which is now heavily modified with a twin turbo system. The combination of my hobbies and my academic success in math and physics made mechanical engineering an almost obvious choice. I have completed internships at Ricardo and Ford, and plan to return to Ford as part of their FCG rotational program.

SECTION 18: Appendices

APPENDIX A - Concept Generation

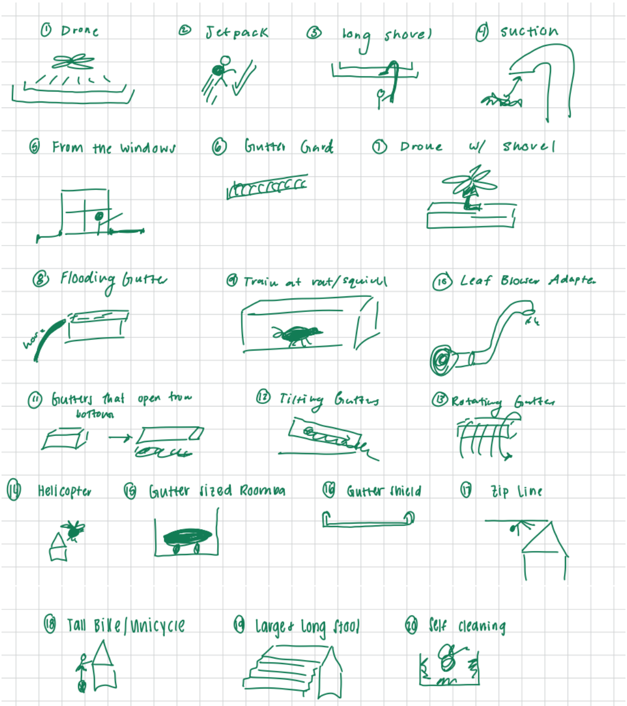


Figure A.1 Concept generation from Daniella Chait's Concept Generation Learning Block

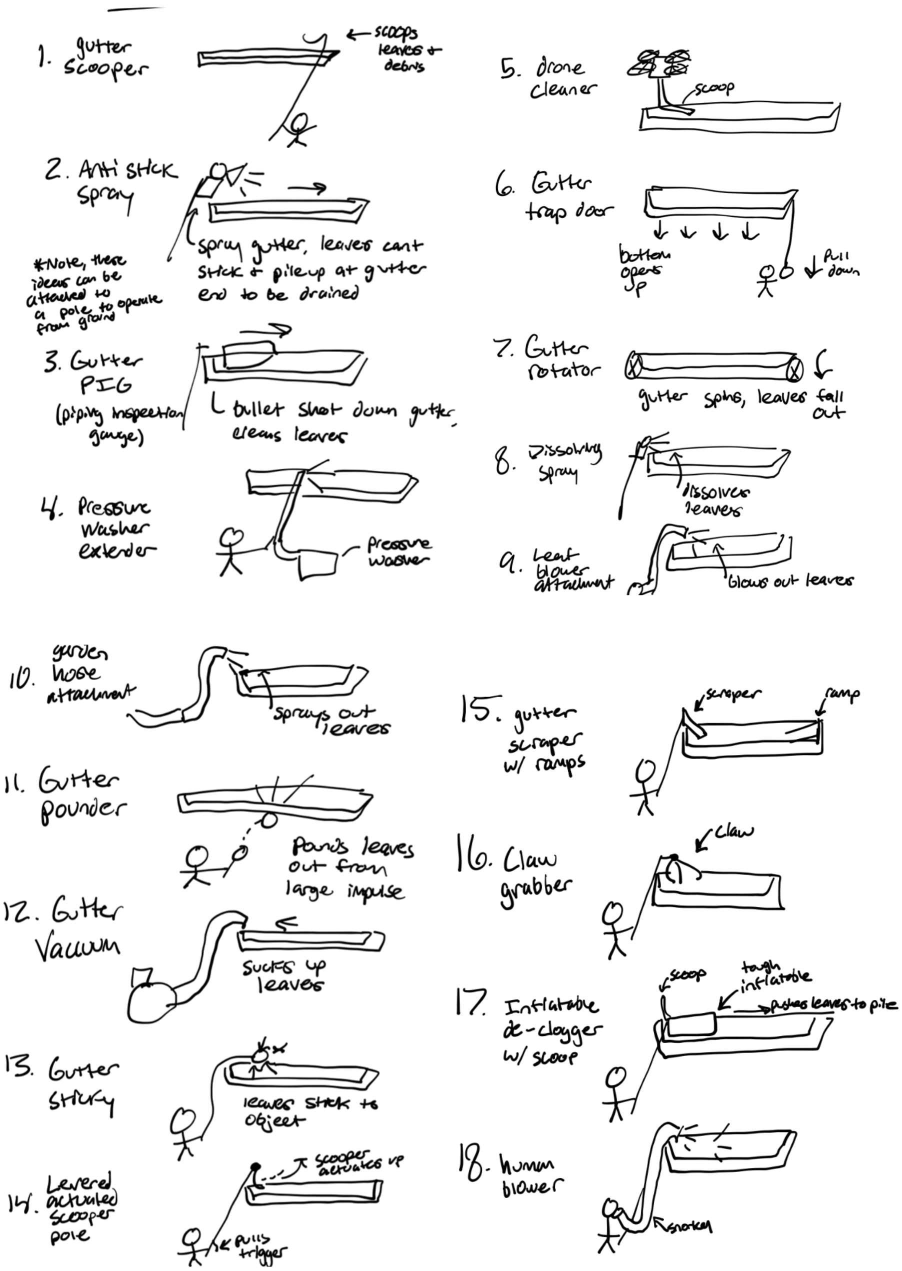
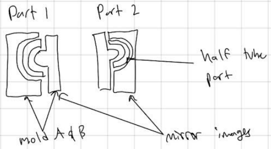


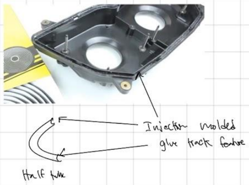
Figure A.2 Concept generation from Max Mancini's Concept Generation Learning Block

① Blow molding air tube to reduce # of parts

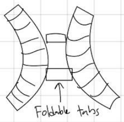
② Injection mold separate halves of tube (not possible to injection mold curved tube in one piece)



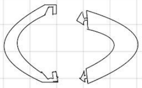
③ Glue track like car headlights to create air tight tube from two halves



④ Single injection molded part which folds to create tube (symmetrical)



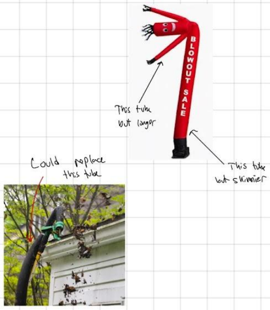
⑤ Injection molded half tubes that snap fit together



⑥ Use existing/ premade flexible plastic air hose instead of sewn nylon tube

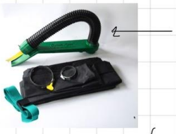
Premade roll instead

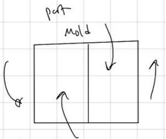
⑦ Find other suppliers of sewn nylon tubes, consider Inflatable Tube Man manufacturers



⑧ Use inflatable tube man to clean gutter by adding holes in correct places

⑨ Use centrifugal casting to create thin wall part



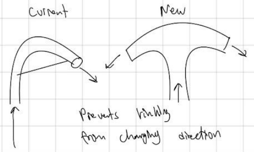


Spin mold in all directions while material cools to create shell of desired shape

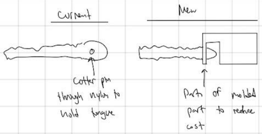
⑩ 3D print assembly as one piece

⑪ Replace nylon tube with Shop vac hose

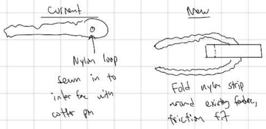
⑫ Make airflow bi-directional



⑬ Injection molded feature to hold nylon tongue

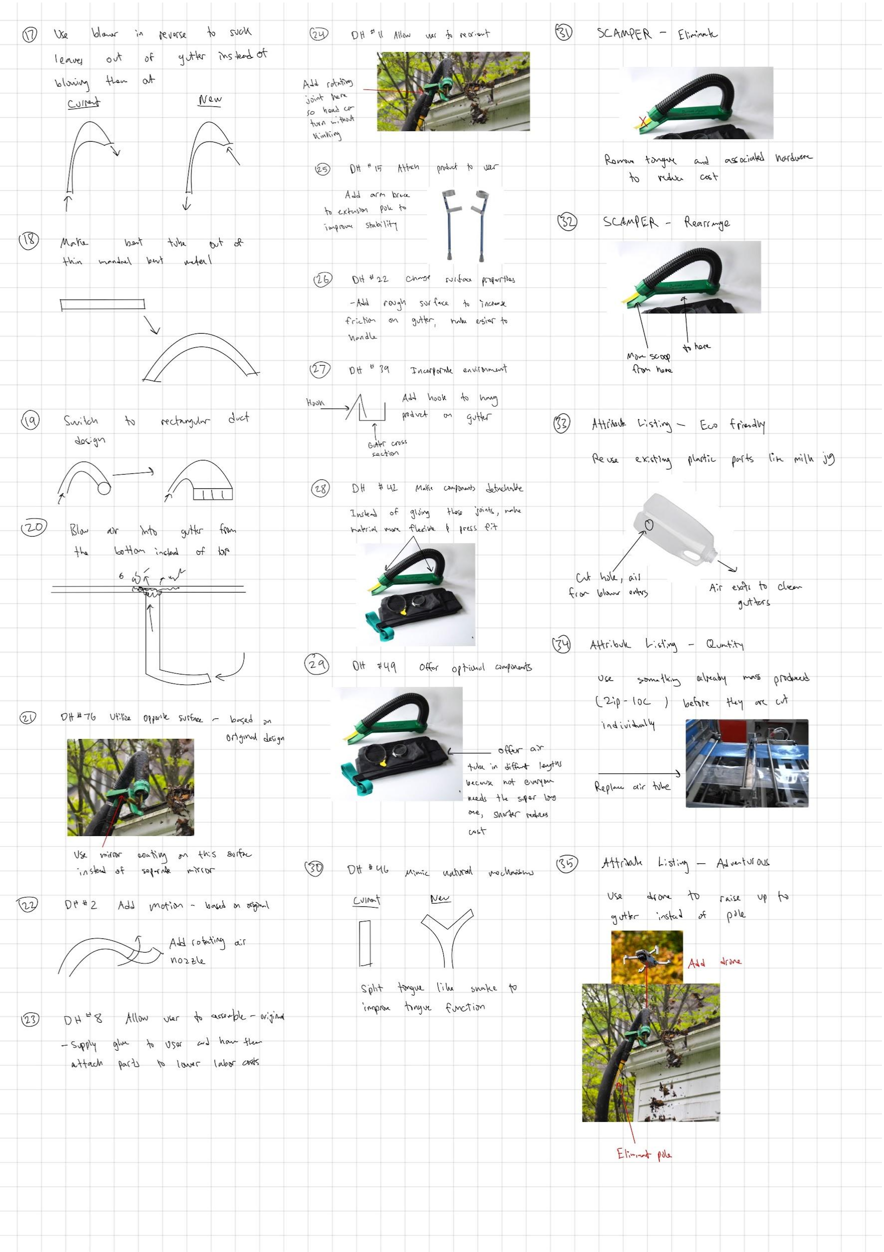


⑭ Use folded nylon to make 2 tongues



⑮ Use compressed air instead of leaf blower

⑯ Instead of tongue to agitate debris, vibrate gutter from outside



⑰ Use blower in reverse to suck leaves out of gutter instead of blowing them out

Current

New

⑱ Make bent tube out of thin mandrel bent metal

⑲ Switch to rectangular duct design

⑳ Blow air into gutter from the bottom instead of top

㉑ DH #76 Utilize opposite surface – based on original design

Use mirror coating on this surface instead of separate mirror

㉒ DH #2 Add motion – based on original

Add rotating air nozzle

㉓ DH #8 Allow user to assemble – original

– Supply glue to user and have them attach parts to lower labor costs

㉔ DH #11 Allow user to reorient

Add rotating joint here so head can turn without kinking

㉕ DH #15 Attach product to user

Add arm brace to extension pole to improve stability

㉖ DH #22 Change surface properties

– Add rough surface to increase friction on gutter, make easier to handle

㉗ DH #39 Incorporate environment

Hook

Add hook to hang product on gutter

Gutter cross section

㉘ DH #42 Make components detachable

Instead of gluing these joints, make material more flexible & press fit

㉙ DH #49 Offer optional components

Offer air tube in different lengths because not everyone needs the super long one, shorter reduces cost

㉚ DH #46 Mimic natural mechanisms

Current

New

Split tongue like snake to improve tongue function

㉛ SCAMPER – Eliminate

Remove tongue and associated hardware to reduce cost

㉜ SCAMPER – Rearrange

Move scoop from here

to here

㉝ Attribute Listing – Eco friendly

Reuse existing plastic parts like milk jug

Cut hole, air from blower enters

Air exits to clean gutters

㉞ Attribute Listing – Quantity

Use something already mass produced (zip-loc) before they are cut individually

Replace air tube

㉟ Attribute Listing – Adventurous

Use drone to raise up to gutter instead of pole

Add drone

Eliminate pole

Figure A.3 Concept generation from Holden Collins' Concept Generation Learning Block

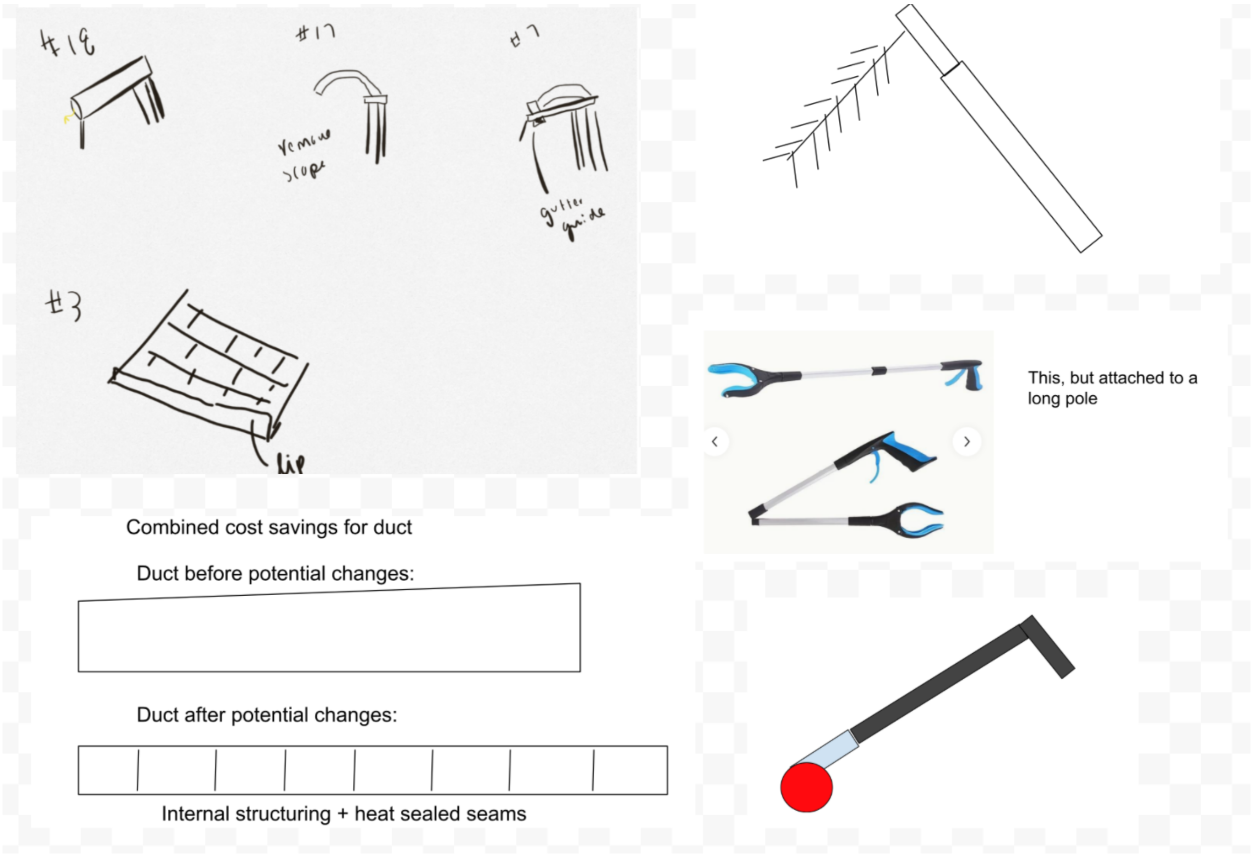


Figure A.4 Concept generation from Jackie Henrietta's Concept Generation Learning Block

SECTION 19: Build Design Bill of Materials

Table 8.3: Build Materials

Material	Parts	Source	Manufacturer	Part Number	Cost
PLA	Left Shell Right Shell Sled Nozzle	Purchased	Matter Hackers	M-SM7-3QYQ	$20.87
Nylon	Tongue	Purchased	Sailrite	100NYLWBK-FT	$0.30
Rip Stop (Nylon)	Air Tube	Provided by sponsor	—	—	—

SECTION 20: Manufacturing/Fabrication Plan

ABS Continuation

10. 3D print the manifold
    a. Split manifold into smaller parts as needed to fit in printer build area
    b. Print each part in PLA
    c. Glue each 3D printed part together
11. Sew air tube
    a. Cut Ripstop into 1’x20’ rectangle
    b. Fold rectangle in half and sew along seam
    c. Fold over top and bottom, hem each (inlet and outlet)
12. Cut and install tongue
    a. Cut 1’ of nylon webbing
    b. Feed tongue through one slot from the inside of the outlet, cross over to the other slot along the top of the outlet, and feed tongue into the other slot from the outside.
    c. Pull tongue through slots so each side is even
13. Install air tube
    a. Place air tube around inlet
    b. Clamp air tube to inlet with hose clamp

Ripstop Continuation

14. 3D print sled and nozzle
    a. Split sled into smaller parts as needed to fit in printer build area
    b. Print each part in PLA
    c. Glue each 3D printed sled part together
15. Assemble sled and nozzle
    a. Align slots in sled and nozzle
    b. Feed zip tie in one slot from the outside and out the other
    c. Tighten zip tie
16. Sew air tube
    a. Cut Ripstop into 1’x20’ rectangle
    b. Fold rectangle in half and sew along seam
    c. Fold over top and bottom, hem each (inlet and outlet)
17. Cut and install tongue
    a. Cut 1’ of nylon webbing
    b. Feed tongue through one slot from the inside of the outlet, cross over to the other slot along the top of the outlet, and feed tongue into the other slot from the outside.
    c. Pull tongue through slots so each side is even
18. Install air tube
    a. Pull air tube through 4” diameter loop in sled
    b. Place air tube around nozzle and fix with hose clamp
    c. Fix air tube grommet to hole in sled