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MEC 825 – Mechanical Design

Final Project Report

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Portable Green Coffee Bean Destoner

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Abstract

The goal of this project is to design and prototype a modular and portable coffee bean destoner that can effectively and reliably separate coffee beans from stones. The system uses a unique airflow based system rather than typical vibration techniques to complete the separation from the denser stones. It is designed as a countertop appliance thus, quiet operation and a compactness are prioritized. The system leverages aerodynamic differences between stones and coffee beans to separate the two, ensuring product quality and protection of downstream coffee grinding equipment. With a target budget of $100, various cost-effective components were selected and extensive 3D printing was used for fabrication of the structure. The result is an affordable, accessible, optimized, and fully-functional prototype that is appropriate for small-scale home roasting applications.

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Chapter 1 - Introduction

Efficiently separating impurities such as stones and debris from green coffee beans is a critical challenge in coffee production. Impurities not only lower product quality but can also damage downstream processing equipment, increasing costs and downtime. To mitigate these risks, the implementation of a coffee bean destoner is essential. Manual sorting, which is time-consuming, labor-intensive, and prone to human error, is frequently used in traditional ways of eliminating these contaminants. As technology advanced over time, many other design methodologies were implemented to prevent the constraints involved within manual sorting. These impurities can harm grinding machinery, jeopardize the quality of finished coffee products, and most importantly impact the safety of the consumer if they are not eliminated. To address this issue, this project intends to design and build a low-cost coffee bean destoner prototype that effectively separates these impurities by utilizing an airflow-based separation system instead of conventional vibration-based techniques as seen through the industry. With the constraint of a total budget of $150, incorporating a fan-based system is reasonable for the most effective approach as current traditional models within the industry have a generous amount of mechanical components. These mechanical components cause a significant increase in manufacturing costs, maintenance, and production/labour time. Considering the simplicity of a fan-based design system, material selection would be quite simple due to the only main emphasis being on durability and affordability. By using materials that fit these constraints, the prototype shall remain functional and perform effectively for a long period of time without the need for frequent maintenance or repairs. The main goal for this project is to develop a product that allows individuals who roast their own coffee an option that is effective, portable and reasonably priced to improve coffee quality and protect coffee grinding equipment.

As technology developed overtime, various design methodologies came about to combat manually sorting during the coffee destoning process. In centralized mills, dry cherry or parchment coffee is typically cured on a concrete pad where contaminants such as stones are introduced. These impurities are eliminated using densimetric vibrating tables, oscillating screens, and a pneumatic "catador" that can detect size and density discrepancies between the beans and unwanted debris. Finally, a centrifugal mill, typically a ribbed steel drum or a crossbar rotating in a perforated casing, is used to dehull the dry parchment or shell, which becomes brittle when dried [1]. Similarly, the use of vibrational analysis can be portrayed through the design and construction of an electrically powered coffee roasting machine that incorporates a destoning mechanism. This machine in particular used a vibrating screen to separate stones and other debris from the beans before roasting. By doing this, the machine was able to leverage the differences in particle size and weight to achieve effective separation [2]. Presently, the use of mechanical separators that separate coffee beans from unwanted debris has become a popular strategy. Another study was conducted through analyzing the design and construction of a coffee threshing machine which used a combination of impact and frictional forces. The machine's concave mechanism and threshing drum efficiently separated the beans and debris according to their variations in size and density [3]. The implementation of these designs require extensive research and calculations to be done with the addition of having higher costs as well. Another research was conducted within the Cocoa Research Institute of Nigeria which heavily focused on a dehulling design using available local materials. Amongst the detailed research and observations, it was concluded that this dehulling machinery was able to increase the dehulling efficiency, and cleaning efficiency while decreasing bean damage. This was done through incorporating a centrifugal fan that generates an air current which separates lighter coffee beans from heavier debris. The design considered factors such as air velocity and flow rate to optimize the separation process. “Considering the reasonable performance achieved at a wide range of the machine operating conditions, this work has a good prospect for commercial coffee production”[4].

Amongst the many design methodologies used to separate coffee beans from impurities, the design within this report will analyze an approach that is similar to the dehulling machine and a fluidized bed system. Taking the approach similar to the dehulling machine, the design of this prototype under analysis will incorporate a fan propulsion system that will generate enough air to propel lighter coffee beans into a separate compartment, while other heavier and more dense debris such as small stones will fall directly into another collection compartment. This system puts heavy analysis on the mass and aerodynamic properties of the coffee beans which has already been proven to work and is a largely incorporated technique in many coffee processing systems. Using a fan-based system has a number of monetary and practical benefits. Fans can be used for projects with a tight budget because they are typically readily accessible and reasonably priced components. Furthermore, the lack of intricate mechanical components lowers upfront and possible maintenance costs. This method works well for destoning coffee beans while also taking into account resource and time limitations. The mechanics behind this design is very simple and straightforward. The air current carries the lighter coffee beans into a seperate collection bin as the debris and coffee bean mixture enters the airflow via a funnel. Stones and other denser particles, will fall into a different compartment directly below and are less impacted by the airflow because of its density. Without the use of vibration-based machinery, this technique effectively separates the beans from undesirable debris and results in a smooth processing system. Another approach that will be analyzed for the final model of this prototype is based on the principles found within a fluidized bed system. This technique uses density differences to separate substances by suspending particles in an upward flow. Heavier/denser stones and debris would stay toward the bottom of a coffee bean destoner machine, while low-density/lighter beans would be elevated in the air column. Unwanted debris can easily be separated from the beans due to this height difference. Key elements influencing efficiency, such as airflow rate and particle size fluctuation, are focused on within a fluidized bed system, such as Zhou et al. 's work on particle motion in a dry separation system. The method can increase separation efficiency and reduce the possibility of denser unwanted debris being mixed with the beans by optimizing airflow. Although more extensive research and calculations may be needed, this approach will still complete the project's objective efficiently and cost effectively without the use of vibration-based machinery.

Chapter 2 - Literature Review

2.1 - Aerodynamic Properties of Coffee Cherries and Beans

As mentioned in the introduction of this report there are two design concepts that are being considered to separate the green coffee beans from the stones. The first involves slowly dropping the beans and blowing them using a fan at a critical speed that blows the beans into the collection bin and allows the stones to drop into the waste bin. The second design concept involves separating the coffee beans from the stones by using a fan to suspend the beans to a certain height where they can be collected. Both design concepts require a deeper understanding of the aerodynamic properties of arabica coffee beans that is provided in this review. The working thesis that allows this process to work is that the beans and the stones are approximately the same size as they had already gone through a sieving process to remove the stones that are larger than the beans. The remaining stones are approximately the same size but much more dense than the beans resulting in the mass of the stones being much greater than the mass of the beans. Based on these assumptions that leads to the thesis that there must be an air speed that is able to suspend the beans without lifting the stones or push the beans further than the stones allowing for a distinct separation between the two items. To determine what this air speed is, the aerodynamic properties of the coffee beans need to be understood, including their drag coefficient, terminal velocity, turbulence and relative sphericity. All of these parameters are related to one another and will affect what the required air speed will be.

The journal article *Aerodynamic properties of coffee cherries and beans* by Afonso Junior et al. explore these concepts for various types of coffee cherries and beans to provide a foundational understanding of the aerodynamic properties of the coffee beans. Firstly, the paper explores the concepts involved in determining the terminal velocity of an object given the density of the object (in this case a coffee bean) and the density of the fluid (air). From there an equation of the turbulence of the fluid (Reynold's Number) and how it can be used to determine the drag coefficient of a spherical object. Coffee beans are not completely spherical therefore a representation of the sphericity of the bean was determined using the orthogonal dimensions of the bean. With the parameters set for determining the theoretical terminal velocity of the beans and cherries the experimental terminal velocity of both the beans and the cherries were tested using a centrifugal fan, a diffuser and apertures to measure the airspeed. To determine the true density and volume of the coffee beans the calculations were performed assuming the beans were semi-spherical. The results of the experiment provide an expected drag coefficient of the Catuai bean (Arabica Bean) of approximately 0.49 based on the regression equation which takes into account various moisture contents which affects the overall density of the beans. This value is independent of the turbulence of the air flow and was tested for an individual bean.

One of the shortcomings of the experiment is that it only provides experimental values for the drag coefficient and terminal velocity of a singular bean. The effects of suspending multiple beans at a time which is what will take place during the operation of the coffee bean destoner. The air flowing from beneath the beans to suspend them will be disturbed and redirected by each bean resulting in random airflows affecting the height of each suspended bean. This problem will need to be tested throughout the development of the prototype. Some potential solutions include designing for differences in bean size, shape and density.

The theoretical and experimental terminal velocities are helpful to determine the airspeed that the fan needs to be able to provide to keep the beans suspended at a constant height. The terminal velocity of an object occurs when the force of gravity and the drag force (in this case the force of the air suspending the beans) are equivalent resulting in no acceleration (an object at a constant speed or an object at rest). Based on the results published in the paper the terminal velocity of the arabica beans range from 7.88 m/s to 9.92 m/s depending on the sphericity and the moisture content of the beans. The results of the experiment show that the terminal velocity of the beans can become more consistent if the moisture content of the beans is controlled. Therefore, as long as the beans remain together in a consistent environment they should have similar moisture contents resulting in similar densities. [5]

2.2 - Investigation of Particle Motion in a Dry Separation Fluidized Bed Using PEPT

Suspending a singular coffee bean using air is a simple process, the drag force needs to be equivalent to the force of gravity acting on the bean. This process is similar to how a fluidized bed system operates. The concepts outlined in the journal article titled Investigation of *Particle Motion in a Dry Separation Fluidized Bed Using PEPT* by Zhou et al. describes the mechanics of how the system works. Based on this description the mechanism behind the fluidized bed system can be applied to a coffee bean destoner based on various criteria outlined in the journal. The working theory behind the fluidized bed concept in its application to the coffee bean destoner is that the low density coffee beans will be suspended or lofted higher that the high density stones that have been missed in the sieving process. With the difference in height separating the beans from the stones the beans can be easily collected. In addition to determining the separation process the article explores how varying airflow affects the separation efficiency of the high and low density particles. This will provide a deeper understanding of the operation of the system and allow for the speed of the airflow to be optimized for maximum separation of the beans and the stones.

The study investigates the motion and separation of particles in a dry gas-solid fluidized bed, using positron emission particle tracking (PEPT) to track the movement of individual particles. The goal of the experiment is to improve dry separation techniques that are used in mining and material processing to reduce the reliance on water-separation methods that are the standard practice in these industries. The fluidized bed being analyzed in the study contained quartz (low density) and hematite (high density) which would be separated to determine the separation efficiency. PEPT tracking was used to record the motion of the particles in the fluidized bed where the airflow rates were varied to compare their effect on the separation of the two particulates. Along with varying airflow rates the size of the particulates were also changed over the course of the study. The outcomes of the experiment showed that dense particles would settle at the bottom of the fluidized bed while lighter particles would remain suspended in the fluid. Higher airflow rates would reduce the efficiency of the separation because heavier particles would remain suspended for longer periods of time. Therefore, the study concludes that fluidized beds are effective for density-based separation, but airflow optimization is crucial to ensure separation between the low and high density particles. The outcomes of the experiment provide the team with confirmation that the design concept is possible and outlines the primary challenge that will be faced during the development of the coffee bean destoner. The primary challenge will be determining if the airflow rate is optimized to properly separate the stones from the beans.

The primary shortcoming of the paper when being applied to the fluidized bed coffee bean destoner concept is that it does not explore the effects of variations between bean sizes. In a bag of coffee, the beans will have some variation in terms of sizing as a result of beans being broken, or natural deviations in size between individual beans. The team does not have any information regarding how the destoner will be able to handle slight or even significant variations in bean size. There may be difficulty separating beans of different sizes because the fluidized bed may result in smaller stones being mixed in with larger beans that are suspended instead of having a distinct separation between them. This can result in stones making it through the destoning process while the larger beans are discarded as waste with the stones. This will have a negative effect on the yields that one would expect from a half pound bag of coffee.

The research shows that through PEPT density based separation for separating particles varying in density is not only possible but is effective using fluidized beds. Management of airflow and quantity of beans being sorted at a given time is imperative in ensuring that the minimum airflow rate is applied in the system to maximize the efficiency of separation between the beans and the stones. [6]

2.3 - Control Systems

Control systems are the backbone of any automation process. They observe and aid the system to adjust if the conditions are altered. Vsevolod M. Kuntsevich, a renowned expert in controls theory, provides a comprehensive analysis of modern control techniques and their practical applications. His work covers both theoretical foundations and practical examples, and provides readers with a guide to understanding the design and implementation of control systems. In destoning coffee beans, the system must react to unexpected situations like sudden changes to beans flow rate, air pressure, and quantities and composites of impurities. Adaptive control techniques allow the system to achieve balance autonomously enhancing performance and reducing system downtime. PLCs are reliable but too large and expensive for small-scale installations that would be implemented in a coffee bean destoner of this form factor. Embedded controllers are better suited to the application of a green coffee bean destoner that is prioritizing a compact form. The advantages of embedded controllers is that they're easy to reprogram, flexible in their functionality, and are energy efficient. This type of system simplifies hardware design while offering greater flexibility than a standard PLC. Stability Analysis of Controlled Supply Network declares that regional controllers and on-time feedback do not cause this because they keep all things stable. On-time adjustments keep the system stable and in operation effectively. While Vsevolod M. Kuntsevich thoroughly explains control systems and their applications, the book lacks in depth exploration of modern AI driven control strategies that are becoming increasingly relevant. Additionally, it offers limited examples specific to small scale operations but served as a foundation in many ways for the commencement of the design of the control system. Despite the shortcomings within the book, there is a vast array of knowledge that can be applied to the design of the control system. [7]

2.4 - Industrial Process Sensors

Sensors are the ears and eyes of the system; they monitor temperature, pressure, level, air flow and many more parameters to ensure systems operate effectively. David M. Scott, an experienced physicist and expert in industrial sensing technology, provides a comprehensive guide on sensor technology and its applications to process control. His work emphasizes the importance of accurate measurements for maintaining stability and improving efficiency across various industries. Many sensors are discussed by David M. Scott, each playing a vital role in process control. Process sensors fill, such as thermocouples and infrared thermometers help prevent overheating, which is essential for accurate control. Pressure sensors provide airflow and pneumatic pressure, and strain gauges monitor mechanical stress on vibrating elements. Capacitive sensors can detect solid material volume, and ultrasonic sensors offer non-contact liquid and bulk material level measurement. Ultrasonic sensors are best for precise monitoring of flow rates, and differential pressure sensors detect changes in airflow promptly. It is easier to detect clogs early and avoid major issues later on. The system still operates efficiently with these sensors and keeps running smoothly without constant manual intervention. While the literature provides an excellent overview of various sensor technologies, it lacks detailed coverage of modern smart sensors that utilize real time data analytics for predictive maintenance. Additionally, more practical case studies on integrating these sensors into small scale systems would enhance its relevance to the proposed application of counter top coffee bean destoners. [8]

2.5 - Human-Machine Interface Technology Advancements and Applications

Human-Machine Interfaces (HMI) are another critical element of the coffee bean destoning system. They allow complexly designed commercial products to be simple and intuitive to users of all backgrounds. Ravichander Janapati, gives great explanations of how modern HMIs are designed to enhance user experience with features like real time monitoring, predictive alerts, and touch screen interfaces. These features simplify system control and improve productivity in many applications and industries. Modern HMIs are engineered with touchscreen operation, real-time alert, and monitoring features that enable operators to utilize equipment more efficiently. Waste cartridge reminder and block detection features are crucial in keeping operations on small-scale installations and appliances such as in a coffee bean destoner. Users will be alerted when the waste tray is full or when there is any clogging of the hopper so they can address issues as they arise. You can start or stop the machine, adjust settings, or set reminders for maintenance within minutes simplifying the user's experience. These small details yield great returns on improving maintenance of machines ensuring they run reliably. It is especially beneficial for busy cafes and home roasters who cannot afford lost time or would like a stress free way to protect their expensive grinders from stones that make their way into their bagged coffee. While Janapati provides a great explanation of the advancements of HMI technologies the book lacks when it comes to demonstrating practical implementation strategies for small scale industries. The book would also benefit from more real world examples and cost analyses to help operators understand how to balance advanced features with budget constraints in industry. [9]

2.6 - 3D Printing: Processes, Materials and Applications

Srinivasan et al. (2021) give an excellent overview of additive manufacturing techniques. They detail four major techniques: FDM-Fused Deposition Modeling, SLA-Stereolithography, SLS-Selective Laser Sintering, and DLP-Digital Light Processing. Each process varies in cost, resolution, and material compatibility. FDM is popular because it is cheap and easy to use, with most printers operating with thermoplastics such as PLA and ABS. While great for rapid prototyping, the surface finish and poor detail make it less ideal for high-precision jobs. In contrast, SLA and SLS offer higher detail and strength. SLA cures resin with UV light, producing smooth finishes but brittle parts. SLS uses lasers to sinter powdered materials like nylon into robust, complex parts with no supports, hence, suitable for industry. Selection of the material is one of the most important issues in 3D printing. The literature presented covers a broad base of basic thermoplastics, advanced composites, and metal powders for improved strength and functionality; even multi-material printing enables the achievement of parts with different properties. However, the research is theoretical and lacks practical data and examples for application, especially in fields such as food processing, where parts should resist stress, high temperatures, and strict hygiene standards. Further research should test 3D-printed components in real settings, especially in sectors involving coffee processing, where equipment durability and food safety are paramount. [10]

2.7 - Waste Management in the Coffee Industry: Sustainable Practices and Value Addition

Murthy and Madhava Naidu (2012) discuss waste management in coffee processing, focusing on environmental impacts reduction and valorization of by-products. The wastes generated during the processing of coffee include pulp, husks, silver skin, parchment, and spent grounds. If not handled properly, these by-products can cause pollution and methane emissions. It discusses the biochemical composition of such by-products, necessary in order to find reuse strategies. Rich in organic material, pulp, and husks fit for composting; caffeine and polyphenol content is toxic to plants, so a necessary pretreatment like leaching or microbial inoculation is required. The authors point out that anaerobic digestion is one of the ways of producing bioenergy from coffee waste, yielding biogas as a renewable energy source. Mucilage and pulp of coffee are rich in carbohydrates, hence having high methane potential. In addition, direct combustion of dried coffee husks can be used as a simple heat source, especially in areas with limited access to conventional energy. Beyond energy, value-added products can also be produced from by-products of coffee. Spent grounds rich in antioxidants and dietary fiber are used in food, cosmetics, and pharmaceutical industries. The new value of waste coffee ground includes manufacture of bioplastic, biochar, and even construction material. While the paper has a wide scope, it does not consider the economic viability of these approaches, particularly for small-scale producers. Some technologies, such as bio-compound extraction and bioplastic production, are expensive. Moreover, environmental trade-offs in the involved processes, including drying and processing, are not considered. Future research may focus on the juncture between agricultural and manufacturing waste management by examining wastes produced in 3D printing of coffee machinery. This will provide a more holistic and integrated approach to wastes. [11]

2.8 - Energy Consumption in Coffee Bean Roasting

Schwartzberg et al. (2013) discuss energy consumption in batch roasting of coffee. Energy consumption is categorized into preheating, roasting, and cooling stages to determine the stages at which inefficiencies occur. This work has focused on heat transfer through radiation, conduction, and convection; hence, a major source of energy loss has to do with the generation of waste heat. They then recommend recovering waste heat methods that could capture, and reuse waste heat generated within one stage of roasting for efficiency in another stage. It also explains several heat exchanger designs and materials for the optimization of energy use. The other points of the study are automation and control systems. Real-time monitoring allows precise adjustments in temperature and airflow, enhancing roast quality without energy waste. Thus, automated systems can change based on real-time data, greatly reducing energy consumption. The optimization process includes adjustment of batch size, decrease in roasting time, refining cooling methods, which secures long-term energy savings; proper maintenance and upgrading of equipment periodically are also important to maintain the efficiency. The study targets roasting on small-batch levels, which means its results cannot be generalized to larger industrial setups. Roasting systems that consist of continuous roasters that are the main use in commercial roasting plants are not included. Future studies would be extended to incorporate energy consumption throughout the whole chain of coffee processing including destoning and grinding. Applying energy-saving measures on all levels of processing may add more significant overall effectiveness. [12]

2.9 - Literature Review Summary

The literature review was an essential part of the design process that allowed for the team to acquire a deeper understanding and appreciation of the project at hand. Firstly, research was conducted on the physics and mechanics the device would require to separate stones from the green coffee beans. The first article (section 2.1 of the report) helped provide the team with information regarding the aerodynamic properties of green arabica beans. This understanding gives the team values for the drag coefficient, terminal velocity and density of the coffee beans that is necessary to perform mathematical calculations, modelling and simulation of the system. The second article (section 2.2 of the report) provided the team a deeper understanding of the fluidized bed system that would allow for the separation of stones from coffee beans by suspending them with an airflow. This article also addressed one of the main concerns the team had with the first source in that it allowed the team to understand how airflow would affect quantities of beans rather than just one. The third article (2.3 of the report) emphasized how control systems provide stability and adaptability. It provides helpful information on understanding adaptive control techniques and embedded controllers to maintain stable and efficient operation for coffee bean.The fourth article (2.4 of the report) provides an excellent overview of various kinds of sensors used in the industry. This article helps understand different kinds of sensors and their use cases. It provides the team valuable insights into selecting and understanding sensors for the project. The fifth article (2.5 of the report) goes in depth on Human machine interface and the importance of having user friendly interfaces. It highlights how intuitive design, real time alerts, and ease of use can significantly enhance operator efficiency and reduce operational errors.

Chapter 3 - Cost Breakdown

Table 3.1 - Design Cost Breakdown

Item	QTY	Cost (CAD)	Justification
12V Power Supply	1	$21.45	Necessary to give the system steady electrical power. Fewer less expensive options without compromising performance.
Blower Fan	1	$21.46	Essential for controlling airflow to enable efficient separation. There was insufficient airflow in lower RPM options.
Power Splitter Cable	1	$10.16	Allowed for efficient power distribution, reducing the need for multiple power sources.
IRLZ544N MOSFET	1	$18.06	Used for efficient power switching, allowing precise control of the blower fan. Replaced more expensive control components, reducing overall cost while maintaining system functionality.
1N5818 Diode	1	$9.00	Prevents backflow of current, protecting the circuit from potential damage due to sudden power cuts. A necessary component for circuit reliability at minimal cost.
PLA+ Filament	N/A	$40	Used to print out the design. PLA+ is tougher and less brittle compared to regular PLA, making it less likely to crack under stress.
Total		$120.13	

Functionality and cost restrictions had to be addressed in order to create a prototype that was feasible. Components were carefully chosen that satisfied the performance requirements while keeping costs to a minimum, working with a $150 overall budget. Purchasing more than needed was required since some material, like the fibreglass window screen, were only available in larger dimensions. Other choices, such as using an at-home available 3D printer and arduino kit also contributed to cost savings. This breakdown shows how much was spent, justification for each purchase, and what could have improved the design with a bigger budget. Despite budget limitations, strategic material choices and cost-cutting efforts allowed the build of a functional prototype while keeping costs low.

3.1 - Cost-Saving Measures

The cost-saving measure that took place within the project was achieved through multiple ways. First, choosing cost-effective components was the main priority. Considering this a prototype design, opting out in quality of material versus performance was implemented in all material selection decision making. The next task was to use available materials and resources. 3D printing the whole design was selected to cut cost down as three 3D printers were readily available to use at any time. This resulted in fast prints and prototyping, saving a lot of time. Additionally, PLA+ filament was selected since its cost is relatively same to PLA, however it offers additional strength and durability. To reduce filament cost, infill percentage of the outer walls were kept around 15% except back end wall and ramp which were printed at 30%, infill due to them going under bore stress from bean impact. 3D Printing the design with a reasonable infill helped keep filament costs low. Furthermore, 3D prints were printed with lightning shape and triangular shape infill which used less filament and also over greater durability. 3D Printing the design with a reasonable infill percentage along with lightning and triangular pattern helped keep filament costs low. By utilizing 3D printers and readily available screws at home, additional hardware expenses and manufacturing time was avoided. By implementing this, the cost of creating or buying the duct and hopper was avoided, with the addition of eliminating the need of buying screws, nuts and bolts, and the handle needed for the collection tray. The final two strategies implemented to save cost was minimizing unnecessary purchases and spending only on essential components. These were completed through the purchase of exact amounts of materials (electrical components) and avoiding unnecessary upgrades such as a display or control modules.

3.2 - Budget Constraints, Unavoidable Costs and Design Improvements with Higher Budget

PLA+ had to be used to 3D print the design, even though cheaper options like regular PLA filament are available. Using filament with good durability and strength was important and unavoidable as some components had to withstand impact of the beans falling on the ramp or hitting the end wall at speed. In a comparable way, some electrical parts, such as the blower fan and 12V power supply, had to satisfy power and airflow specifications, which limited less expensive options. If a larger budget was given, the design can be improved in several ways. First off, the fan system could be significantly more powerful and have a higher adjustability, making the efficiency of the system more enhanced and optimized. High-quality materials will also be purchased such as aluminium and acrylic rather than 3D printed parts, making the durability of the system higher and overall industry-standard. Outsourcing certain design components such as the mesh vent, funnel, or loading ramp would allow for fewer excess in material, reducing the need to purchase oversized stock material and labour time. Finally, strategies in user-friendly upgrades will be implemented such as the use of a touchscreen rather than keypad, which may need to change the functionality of the design, but improve the product's usability.

Chapter 4 - Preliminary Design Concept

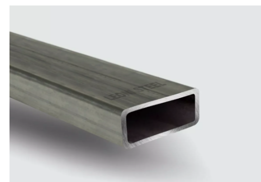
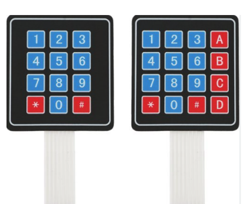
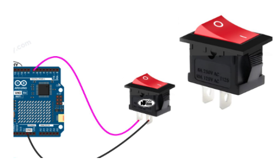
A structured method was used for comparing different potential solutions for every important subsystem when creating the preliminary design. A morphological chart was used to do this, allowing an organized selection procedure that complied to multiple crucial design criteria while striking a balance between functionality, reliability, and overall performance.

The selected solutions for each category were as follows:

- Structural Frame – Solution 3
- Fan System – Solution 2
- Separation System – Solution 1
- Electrical Set-up – Solution 3
- Assembly/Finishing – Solution 3

These choices were affected by a number of factors. The selected components have to be easy to create and put together using easily accessible tools, considering the two-month schedule for designing and creating a functional prototype. Because of the limited budget of $100, it was also necessary to use affordable materials and components without sacrificing functionality. Another important factor was manufacturability because of the lack of access to industrial machinery. As a result, the parts selected have to be assembled with standard shop tools, ensuring longevity within the constraints. Furthermore, because the device is meant for use in the home kitchen, it must be compact and portable, which affected the choice of a smaller structural frame and an efficient fan system that does not take up a lot of space. Durability was also a major concern.The use of PLA+ filament helps ensure that the design is printed with enough strength and durability with repeated impacts. The printed parts will be assembled using super glue, which is easy and cost effective. It provides strong bonding for plastic components without need for expensive adhesives, making it a practical choice under budget constraints. Furthermore, sound reduction was considered when selecting the fan system, with the goal of reducing operational noise while improving user experience. By carefully considering these constraints, this preliminary design serves as a strong foundation for further refinement, ensuring that the final prototype meets both functional and practical requirements within the given limitations.

Table 4.1 - Preliminary Design Morphological Chart

Sub-System	Solution 1	Solution 2	Solution 3
Structural Frame	Lumber 	Steel 	PLA+ 
Fan System	Cooling PC Fan 	Blower Fan 	Mini Axial Fan 
Separation System	Divider 	Mesh Filter Screen 	Mini Push Arm 
Electrical Set-up	KeyPad 	Sensor 	On/OFF Switch 
Assembly	Rivets	Nails	Super glue

4.1 - Preliminary Design Concept

The preliminary design concept involved dropping the coffee beans and stones through a funnel and allowing these beans to be blown by a concentrated airflow provided by a computer cooling fan. The low fan speed would be increased using a duct that leverages the Venturi effect by constricting the airflow to increase the velocity of the air. This increased air speed is designed to push the beans further than the stones based on their density which causes a separation between the two substances. A separation wall was designed to block any of the stones from being blown into the bean collection area as they would be pushed a smaller distance by the fan than the less dense coffee beans. This design concept is shown in Figures 4.1 and 4.2.

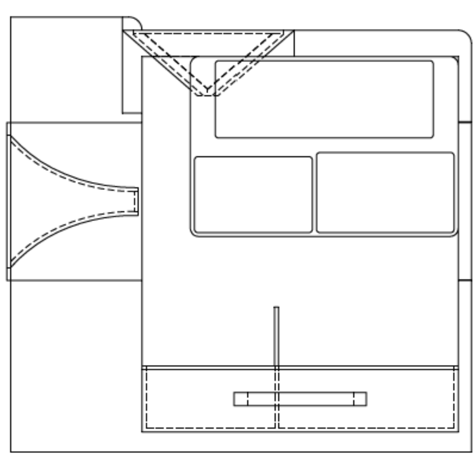


Figure 4.1 - Side View

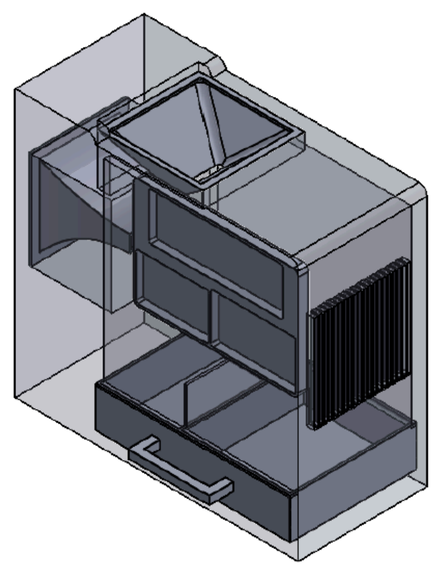


Figure 4.2 - Isometric View

4.2 - Preliminary Design Calculations

To perform the preliminary design calculations the requirements were divided into three main steps. Step 1 was to determine the Force and Time Required to separate the beans based on the aerodynamic properties of the beans and the kinematics of the system in use. Step 2 involved determining the dimensions of the diffuser shape and dimensions based on internal pipe flow equations.

The entire calculation process can be found in appendix C. As seen in the appendix, in order to perform Step 1 the system was divided into three sections as is shown in Figure 4.3. The Yellow region is when the beans and stones are in free fall. Region 2 is the blue region where the beans and stones are blown by the fan and is completed when the separation wall is reached. Lastly, Region 3 represents the height of the separation wall.

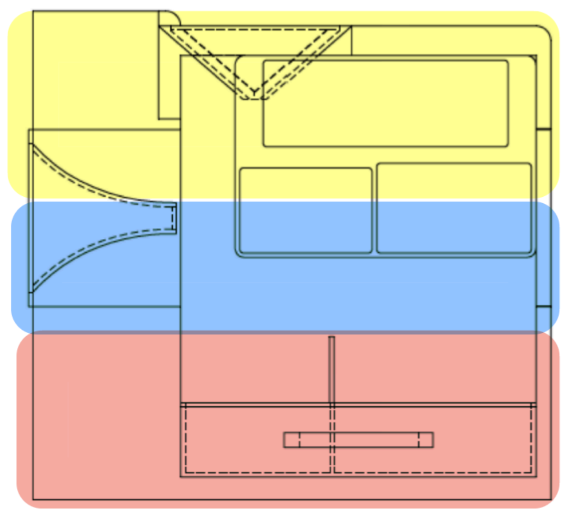


Figure 4.3 - Region Breakdown of the Preliminary Design

Based on the average mass of a bean that will be shown in Chapter 5 of this report, 0.163 grams was chosen to perform the theoretical analysis of the system. The dimensions of the average sized bean was determined to be 10mm in length (a), 7mm in width (b) and 4mm in height (c). These dimensions were used throughout the calculations to model the size of the beans and stones.The average mass of the coffee beans was calculated by taking 100 green coffee beans provided and weighing them using a food scale and dividing the mass by the 100 beans to find the average mass per bean. The average mass per bean was repeated 5 times using the average of 100 beans each time. The average of these five iterations was found to get the average mass of the provided beans. This process is outlined in Table 3 resulted in an average mass of a coffee bean 0.163g.

Table 4.2 - Average Mass of the Coffee Beans

Group #	Total Mass (grams)	Mass per Bean (grams)
1	16.5	0.165
2	15.6	0.156
3	16.9	0.169
4	16.1	0.161
5	16.4	0.164
	Average	0.163

Based on the calculations as seen in appendix C, the Noctua NF-P14 redux 1500 PWM fan should be adequate for the coffee bean destoning application. To further develop this design a Computational Fluid Dynamic (CFD) analysis was performed on the duct to double check the findings.

4.3 Computational Fluid Dynamics Analysis

To further the understanding of how the system will work a CFD analysis on the venturi vent was performed to determine if the initial analysis of the system was accurate. The goal of the CFD analysis was to determine the outlet velocity of the duct and to determine if there are going to be any unexpected pressure differences that can affect the functionality of the system. Air at 20℃ was selected as the fluid being analyzed. An initial surface roughness of 0 was set as this was a preliminary design and a material was not yet selected for the duct. The fluid velocity along the walls of the duct was set to 0m/s and the fluid was assumed to be fully developed in the analysis. The results of the CFD analysis are shown in Figures and data available in appendix D.

As seen in figures in appendix D, the velocity within the duct begins at 3.713m/s at the inlet and increases to 33.420m/s at the outlet. Achieving the desired 28.032m/s plus an additional 20% factor of safety to account for any differences in bean size and shape.

The pressure profile analysis performed on CFD indicated that the pressure within the duct would increase. Within the duct the pressure reached 110,692.30 Pa which is more than the ambient pressure of air at 20℃ which is 101,325.00 Pa. This provided the team with an indication that the current design may not work. To test this the fan was ordered and a control system was designed to test the functionality of the design as will be explored in Chapter 10 of this report.

Chapter 5 - Theoretical Calculations

Given the failures of the previous design, the redesign prioritized implementing a ramp to increase the amount of time the beans would stay in the air flow. Using a ramp also allows the team to control the trajectory of the beans so the design can be optimized in conjunction with the height of the separation wall to improve the reliability of the separation process.

5.1 Assumptions

- Assume the entrance is not sharp therefore there are no minor losses associated with the pipe entrance.
- Assume the surface roughness (ε) of the pipe is $2.5 \times 10^{-5} m$ for a FDM printer using PLA+ filament.
- Assume the air temperature is 20℃.
- Assume the velocity at the surface of the intake pipe and ramp is 0m/s
- Assume the flow is fully developed within the pipe and ramp.
- Assume there is no air resistance caused by the air flowing back off the back panel for the beans and stones while they are in projectile motion.
- Assume stones are the same size and shape as the coffee beans.
- Assume the beans have a moisture content 12.7 w.b.%, a density (ρ) of $785 kg/m^3$ and a drag coefficient of 0.46 [5].
- Assume the stones are gravel and have a dry density of $1680\ kg/m^3$.

5.2 Projectile Motion of the Beans and Stones

The projectile motion of the bean was iterated on a google sheet to by inputting the required displacement in the horizontal direction required for the bean to make it over the wall at 120mm with a ramp angle of 10°. To perform the iteration a velocity of the bean at the exit of the ramp was inputted. To find the horizontal component of this velocity it was multiplied by cos(10°), to find the vertical component the velocity was multiplied by sin(10°). From the horizontal component of the velocity the time that it would take for the bean to travel 120mm (0.12m) was calculated using t=x/v. This time value was then plugged into the following equation to find the height of the separation wall for a given velocity $y = v_{1y}t + \frac{1}{2}gt^2$ where v_{1y} is the y component of the velocity previously calculated, $g = -9.81m/s^2$ which is the acceleration due to gravity and t is the time it would take to get to the wall. These calculations were iterated until the velocity of the projectile at the end of the ramp provided a wall height of -0.03815m. This iteration process shown in Table F.1 in appendix F shows that this wall height occurred when an initial velocity shown in the green cell was set to 1.10809m/s

All calculations completed for the final design are available in appendix F.

5.3 Ramp Acceleration Calculation

As seen in calculations in appendix F, where v_1 is the velocity of the projectile landing on the ramp, v_2 is the velocity of the projectile leaving the ramp (equal to v from the previous step), L is the length of the ramp and a is the acceleration of the projectile on the ramp.

5.4 Drag Force of the Beans

As seen in appendix F, the drag force F_D of the beans were dependent on the mass (m) and the acceleration (a) of the bean on the ramp calculated below.

5.5 Minimum Fan Airflow Velocity

As seen in appendix F, the minimum fan airflow velocity (v_{min}) will depend on the minimum speed required to blow a bean over the separating wall. This will occur when the drag force of the bean, as well as the density of the coffee bean is used in the following equation.

5.6 Drag Force of the Stones

The drag force of the stones was calculated using the following equation where the density of the stones (ρ), the volume of the stones (V) and the acceleration (a) previously calculated were used. The process is available in appendix F.

5.7 Maximum Fan Airflow Velocity

The maximum fan airflow velocity (v_{max})is the maximum speed that is required to blow a stone over the separating wall. Any speed that the fan is run above this speed will result in failure to destone the beans. The following equation was used to calculate this speed.

5.8 Fan Output Calculations at Maximum Speed

The maximum fan output speed (v) occurs when the fan is running at its maximum rated volumetric flow rate (Q). The cross sectional area (A) of the fan outlet is $1.95 \times 10^{-3} m^2$.

5.9 Fan Output Speed Reduction

The flow rate will need to be reduced to apply the right amount of force that will not be strong enough to blow the stones over the separating wall. If stones make it over the separating wall then the machine would fail. Therefore, the fan speed has to be set somewhere in the following speed range $v_{min} < v < v_{max}$, inserting values into this relation yields $0.4132 m/s < v < 0.7324 m/s$. To ensure beans of varying sizes make it over the wall the fan speed will be set closer to the maximum speed. There is not going to be a large variation in the size of stones that are smaller than the average bean size since they would have been removed during the farm sieving process before packaging. The larger than average beans are more of a concern since it would be ideal for them to make it into the coffee side of the separation wall. Therefore a speed of 0.7m/s will be chosen for the fan speed.

5.10 Coded Fan Speed

The fan speed is coded on a 0 to 255 scale. A 0 on the scale represents a fan at rest and 255 represents the fan running at its maximum operating speed. The desired operating speed of 0.7m/s indicates that it is 8% of the maximum operating speed whose value is calculated in the following equation.

Chapter 6 - Simulation/CFD

In addition to the mathematical modelling a CFD simulation of the intake pipe and the ramp was performed to ensure that there would not be any pressure fluctuations or reductions in velocity that will affect the performance of the prototype. The goals of the CFD analysis were to determine the pressure and velocity profiles of both parts which will help the team develop their understanding of the operation of the machine. It provides the team with data to help improve the performance of the prototype.

For the simulation air at 20℃ was selected as the fluid being analyzed. A surface roughness of 25 micrometers was set as a PLA+ material 3D printed using a FDM printer. The fluid velocity along the walls of the duct was set to 0m/s and the fluid was assumed to be fully developed in the analysis. The complete analysis and figures can be found in appendix E.

6.1 First Iteration Intake Pipe

As seen in appendix E, the first iteration of the intake pipe was a cylindrical pipe that was designed to help reduce turbulence of the air within the destoner. It takes air from outside of the machine and provides a route directly into the intake side of the fan. Without the intake pipe the fan would need an airtight wall to separate the inlet from the outlet or it would risk reducing the volumetric flow rate of the fan by reducing pressure within the machine.

Figure E.1 shows the velocity of the air as well as the paths that it will take during operation of the destoner. This first iteration has a strong outlet velocity especially in the middle of the flow as can be seen in Figure E.2. The velocity vectors shown on the intake side (left) in Figure E.1 are not ideal for the operation of the machine. There are areas where the airflow significantly slows down due to the increase in minor losses due to the sharp opening. This is also shown in the pressure profile shown in Figure E.3 as the light green region that surrounds the opening is forced around behind the flange causing an increase in pressure around the inlet. The outlet has a strong velocity profile which is very helpful because this will be mounted to the fan inlet and provide fast moving air without the risk of the pressure dropping too low and not providing the fan with enough air to operate. This intake pipe will need a redesign to help reduce the drop in pressure at the inlet and help improve the inlet velocity.

6.2 Final Intake Pipe

Using the knowledge gained in the first iteration of the intake pipe the next iteration was designed to implement the venturi effect to increase the speed of the air gradually throughout the pipe until it reaches the pipe outlet. The pipe will be wider at the opening which will help to minimize the minor losses associated with the previous sharp entrance.

As seen in appendix E, figure E.4 shows the velocity vectors of the final intake pipe that represents the path that the air will flow during operation of the destoning machine. The path the air takes at the inlet in Figure E.4 is similar to the path taken in Figure E.1 but the air does not seem to make a sudden or sharp turn into the pipe at the edges of the pipe. The outlet velocity profile shown in Figure E.5 improves over the previous iteration. The maximum velocity in Figure E.5 shown in red is 2.714m/s compared to the same region in Figure E.2 where the red colour represents 2.690m/s. The venturi effect allows for the velocity of the airflow to increase at the inlet of the fan providing air more efficiently to the system. There is also less of a pressure difference in the final design of the intake pipe shown in Figure E.6. The pressure stays more constant which helps to reduce issues where the fan is choked by not having enough air to work efficiently leading to a reduction in performance of the destoner.

6.3 Separation Ramp

The goal of the ramp design is to direct the air upwards at a 10° angle to give the fan more time to accelerate the beans and stones. The ramp is designed to have a reduction in cross sectional area as it gets closer to the end to improve the accuracy of the device by reducing the number of beans that are deflected sideways resulting in a lower system performance. The ramp has an open top so the pressure is not as important as long as it stays at a constant value. The exit speed of the ramp will be used to confirm the results of the mathematical modelling and allow for a potentially more accurate coded fan speed to be implemented.

The ramp inlet is mated to the fan outlet and is where the beans begin by getting pushed by the airflow. The velocity profile of the ramp shown in Figure E.7 shows that most of the air will be passed along the surface of the ramp to accelerate the beans and the stones. Some of the air will also escape the ramp through the open top, resulting in a much higher average ramp outlet velocity than what would be expected in reality. The velocity along the bottom surface of the ramp where the beans will be during operation of the destoner ranges from 35m/s to 107m/s. These velocities are what would be expected at the maximum mass flow rate, and will need to be reduced through a reduction in fan speed. The pressure profile shows that the pressure will remain constant along the bottom surface of the ramp until it reaches the sharp opening where there is a sudden drop in pressure. This drop in pressure is due to the fast moving air escaping from the narrow ramp outlet into the free air where it will escape the destoner.

The calculated velocity was approximately 8.761m/s which may seem lower than the maximum 22.605m/s at the ramp inlet, this is due to the reduction in the cross sectional area in the CFD simulation. The ramp inlet is roughly 25mm by 25mm and the fan outlet is approximately 65mm by 30mm. The calculated velocity if it accounted for this reduction in cross sectional area would result in an outlet velocity of about 25m/s. There is about a 10% difference between the calculated inlet velocity and simulated inlet velocity but they are similar enough for the calculated velocity to be accepted until further testing and modifications can take place with the prototype.

Chapter 7 - Electrical Circuit

The circuit involves various components as listed in Table A.1 in appendix A. An illustration of the circuit itself can be seen in Figure 7.1. The fan's + terminal is wired to the screw terminal's +12V so it always has power available. The fan's – terminal goes to the MOSFET Drain, allowing the MOSFET to act as a switch on the low side. The MOSFET Source is connected to the screw terminal's GND, so when the Gate is activated, current can flow and complete the fan's circuit. The Gate is controlled by Arduino pin D3, which allows the Arduino to turn the fan on (HIGH) or off (LOW). A 10kΩ pull-down resistor between the Gate and the screw terminal's GND ensures the MOSFET stays off when the Arduino isn't actively driving the pin (like at startup). A flyback diode is connected in reverse across the fan to protect the MOSFET from voltage spikes caused by the fan's inductive load when turning off. The Start and Stop buttons are connected to pins D4 and D5 and grounded, using the Arduino's internal pull-up resistors to simplify wiring and logic. All GNDs are tied together including the Arduino, MOSFET Source, and the screw terminal GND, ensuring a shared reference voltage, since all parts are powered from the same 12V source.

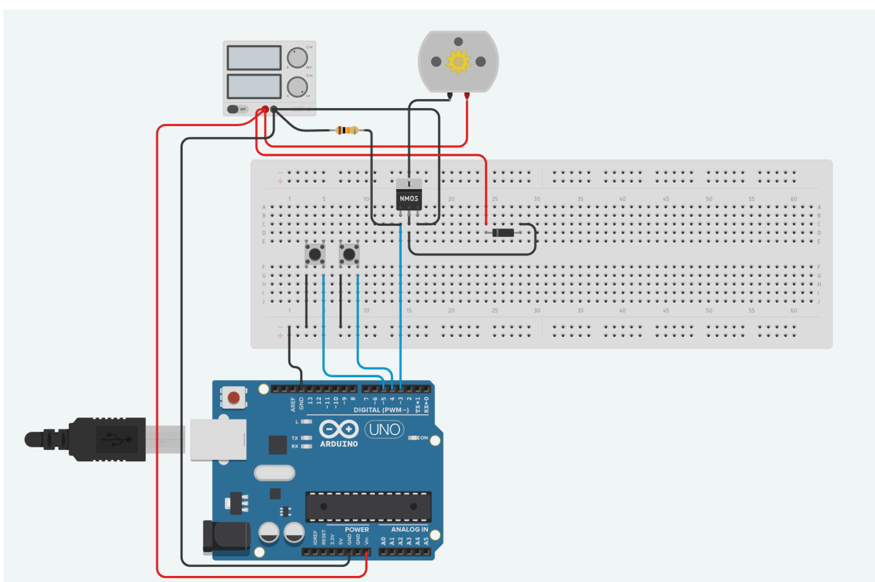


Figure 7.1. Arduino Circuit Layout

The power supply comes through the wall and has a barrel jack ending. Since the appliance requires the fan and arduino to be powered, a Y-Splitter is installed at the end of the adapter's barrel jack to create an extra output. Both of the Y-Splitter endings are barrel jacks, with one going into the arduino to power it on, and the other going into a barrel jack to 2 pin screw terminal block. The screw terminal block has a +12V and a GND, which acts as the power supply for the circuit of this product. The full wiring connections can be found in Table A.2 in appendix A.

Chapter 8 - Human-Machine Interface (HMI) & Programming

The Human-Machine Interface (HMI) for the fan control system is user-friendly and consists of two push buttons which control start and stop. The minimalist setup allows easy usage, making it accessible for a wide range of users, especially for those with limited technical knowledge. The buttons provide immediate feedback, and are distinctable, enhancing confidence and minimizing confusion, to ensure reliable fan operation.

Usability: The system is intuitive, with no complicated settings or interfaces, it's ideal for quick and simple fan control.
Ergonomics: Buttons are positioned at a comfortable height for ease of access, with soft touch reducing strain.
Safety and Feedback: The blower fan noise is used to confirm fan operation, reducing uncertainty in noisy or busy environments.

Accessibility: The buttons are placed at a decent distance apart with clearly distinguishable functionality for each button, making it perfect for users. They are large in size, making it a perfect combination for the visually and mobility impaired.

The code is accessible in Appendix B. It has been created using C++ and Arduino libraries, and can be explained using the following breakdown:

Pin Setup:

- Pin 3 is connected to the MOSFET Gate and sends a PWM signal to control the fan.
- Pin 5 is for the Start Button and Pin 4 for the Stop Button.

INPUT_PULLUP:

- The Arduino uses internal pull-up resistors so the buttons read HIGH when not pressed and LOW when pressed.

Start and Stop Functionality:

- Pressing the Start Button turns on the fan and pressing the Stop Button turns off the fan.

PWM Control:

- The code uses analogWrite() to control the MOSFET using Pulse Width Modulation (PWM).
- fanSpeed = 255 means full speed. You can adjust this value between 0 and 255 for lower speeds.

Control Fan Speed:

- The speed of the fan can be controlled in the code by updating the fanSpeed variable. (Ex: int fanSpeed = 180; // Adjust to 70% speed)

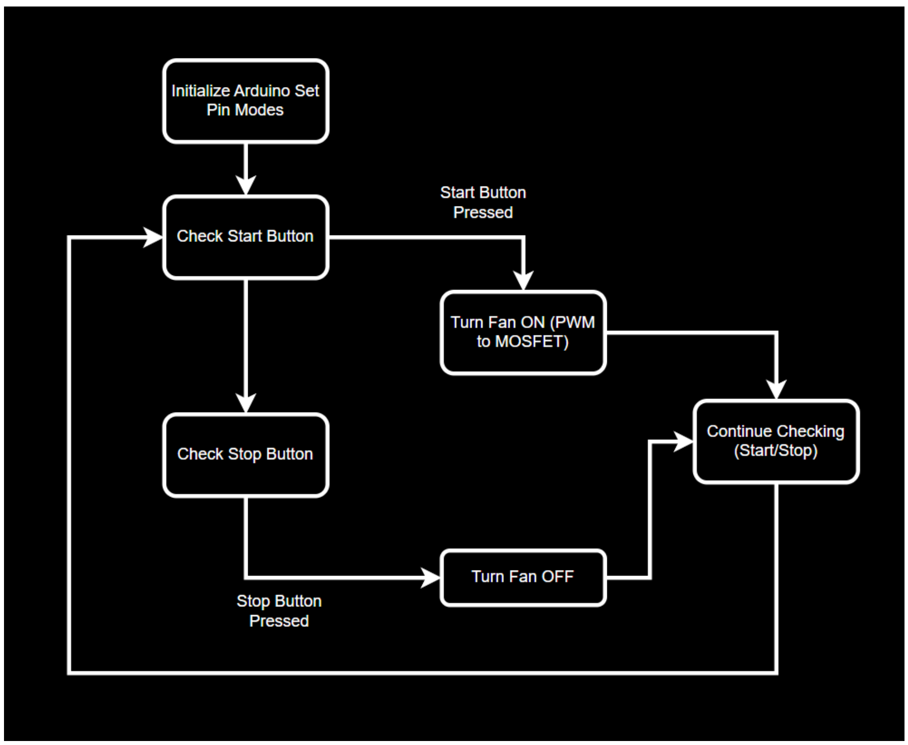


Figure 8.1. Fan Control Flowchart

The flowchart in Figure 8.1 represents the logic for controlling the fan in this product using an Arduino, a MOSFET, and two buttons for start/stop control. This process starts when the arduino initializes its pin modes, putting the fan control pin as an output while the button pins are placed as input pins using internal pull-up resistors. The system checks the state of the start button continuously to see if it has been pressed in order to proceed. Once pressed, the Arduino sends a PWM signal to the MOSFET which turns the fan on at the desired speed specified in the code. The system then loops to check both buttons continuously. Once the stop button is pressed, the Arduino cuts the PWM signal and the fan turns off. The system then proceeds to monitor the start and stop buttons again, waiting to respond to the user input. This feedback loop enables reliable fan control with minimal components.

After pressing the Start button, the user places the beans into the funnel. The beans flow down through the funnel and exit onto a ramp positioned in front of the fan. As the fan powers on, it generates a strong airflow that propels the beans and rocks forward. Due to their lighter weight, the beans are carried further, successfully clearing the wall and landing in the designated bean collection bin. Heavier rocks, unable to travel as far, fall short of the wall and collect in the waste bin. Once the sorting process is complete, the user can press the Stop button to turn off the system. The beans are then gathered from the collection bin, ready for further processing. This automated process ensures efficient separation of beans from unwanted debris with minimal effort.

Chapter 9 - Material Selection

In any design project, the material selection process is crucial since it influences cost, performance, durability, and manufacturability. Using the appropriate materials ensures that the design is functional, long-lasting, and cost-effective. Certain materials can be substituted to save money, while others are just non-negotiable due to their strength or purpose. Making informed decisions early on keeps the project on schedule and prevents issues later. The first step in selecting materials for the build was to break the outer structure into subsections. All structural and internal components were 3D printed using PLA+. Considering the bed size of the 3D printers (220x220x220mm), the outer walls were split into four separate pieces, while the internal components were printed individually such as ramp, funnel and fan support structure. Other filaments like PETG AND ABS were considered, but their higher cost wasn't justified, as the purpose of this build did not require their added strength or temperature resistance. PLA+ offered a reasonable balance between cost,strength and durability whereas regular PLA was too brittle for parts expected to take repeated impact. The next section to analyze would be electrical components and control systems. Although choosing specific materials would be difficult to apply, the ideal material to choose was whichever item performed its function more efficiently. With budget in mind, functionality was the most crucial aspect to analyze within this section, thus the selected 12V power supply, blower fan, diode, mosfet, and an Arduino kit with a start/stop button for the optimized control system were simply chosen for maintaining functionality while cutting expenses. The next major section is obviously the main design constraint, which is the separation system. In order to help separate beans from the unfiltered stones, the separation system used a blower fan, which produced a powerful airflow with a combination of a 3-D printed barrel. To ensure effective passage through the system, the beans were directed into the fan's inlet using a 3D-printed funnel. PLA (polylactic acid) + material was used to print the funnel because it was lightweight, easy to print on, and durable enough to handle the beans. Utilizing PLA + allowed the design of the funnel, ramp, and barrel design to be personalized to maximize separation efficiency while also drastically lowering expenses because the university lab offered free access to 3D printing. A cut-out of fibreglass window mesh screen was used to stop undesired debris from continuing along the airflow channel.

Finally the final section to analyze is the combination of assembly and finishing. This includes the super glue used to assemble the prototype. Overall, the material selection process focused on meeting functional requirements while staying within budget. Alternative materials were considered, but affordability and availability dictated our final choices.

Chapter 10 - Testing & Iterations

Once it became clear that the original design had major limitations, the entire design had to be rethought. The fan alone didn't have enough power to overcome the force of gravity as the beans fell in front of the fan outlet. On top of that, no fan on the market was strong and compact enough to push the beans, which were in free fall, roughly 5–10 cm away and over the wall separating the beans from the stones. These issues made it necessary to redesign not just the fan setup, but the whole process of how the beans moved through the system. The new goal became slowing the beans down as much as possible before they reached the fan opening. This was achieved using a two ramp system. When the beans are dropped from the funnel, they hit the first downward ramp. Upon impact, they lose most of their momentum and velocity. The angle of the first ramp was carefully calculated , it's just enough to allow the beans to slide downward. Since the coefficient of kinetic friction on this ramp is higher than the static friction, the gravitational force pulls the beans diagonally down the ramp rather than letting them get stuck.Next, the beans reach the second ramp, which is angled upward at roughly 10 degrees. When the beans drop onto this ramp, the impact slows them down to nearly zero speed. This was confirmed during testing, when the fan was turned off, the beans simply piled up at the base of this ramp. However, once the fan is turned on, it generates enough airflow to launch the beans like a projectile. Depending on the fan speed, the beans fall approximately 10–15 cm away. The second ramp, although angled upward, does not block the beans. Instead, it helps position them right in front of the fan outlet at low speed, making it easier for the airflow to push them forward. As a safety measure, a mesh was placed in front of the fan opening to prevent any beans that roll backward from entering the fan.

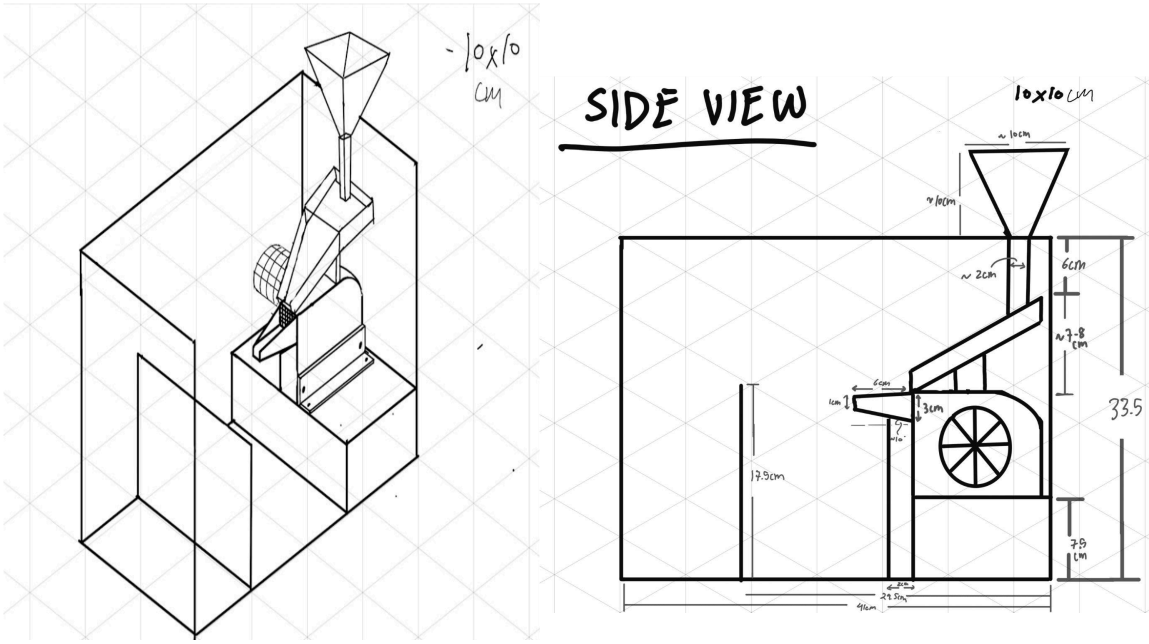


Figure 10.1 - Final Design Prototype Rough Isometric & Side View Drawing

Figure 10.2 - Final Design Prototype Build with Foam Board and Popsicles

Figure 10.1 is a preliminary isometric and side sketch of the final design prototype. The drawings highlight the overall layout, key dimensions, and notable features like the two ramp system, position of the fan, and mesh safety feature. This design was developed to slow down the beans before they reach the fan so that airflow will carry them over the separating wall. The changes made to eliminate earlier design issues are also shown. In addition, Figure 10.2 shows the physical built prototype, created from foam board and popsicle sticks to tangibly experiment with the final design. Followed by the different trials and conclusions that lead to the final design prototype.

10.1 - Testing Preparation and Initial Observations

Firstly, a handful of stones were selected for prototyping, although the final test will be done with stones that are relatively the same size as the beans. Stones of both smaller and larger sizes were also included in the testing to evaluate the system's performance. Below is a picture of the different stones used for testing, along with beans for comparison.

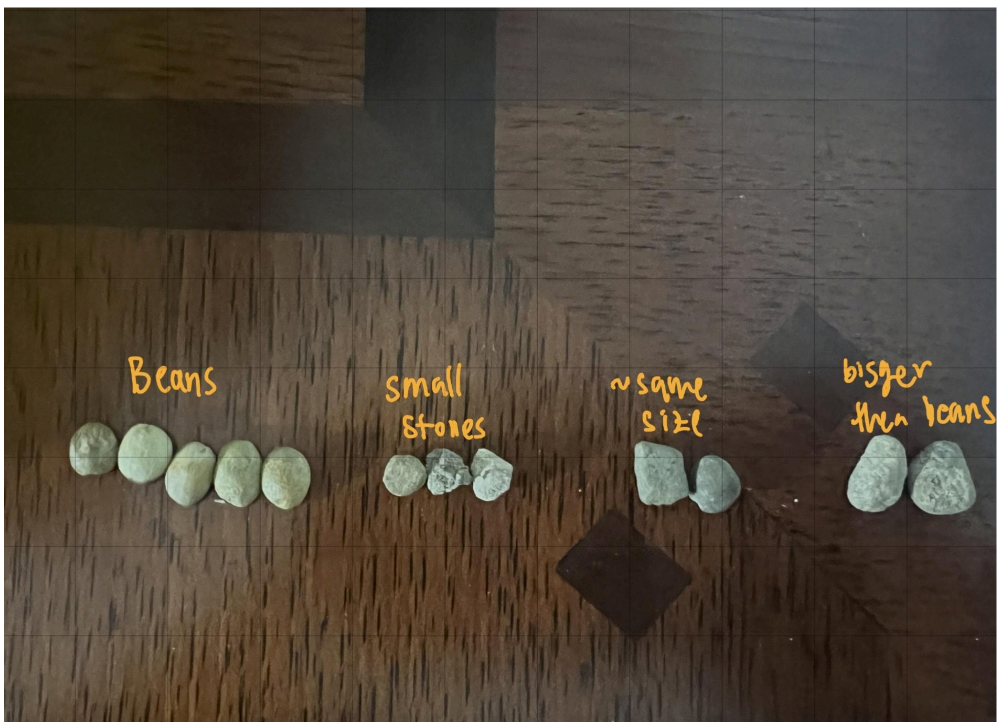


Figure 10.3 - Different Sizes Stones Used During Testing

After selecting a new fan, which had a higher RPM and more importantly, greater static pressure compared to the previous fan that had very low static pressure, testing began with free-fall beans in front of the new fan to preserve the original design as much as possible. However, shortly after beginning the trials, it became very clear that free-fall beans in front of this more powerful fan would not work, as the beans did not even move a centimeter. Furthermore, nothing is available on the market that is compact and would work effectively for free-fall beans. After this realization, it became clear that the only way for the fan to push the beans away was by slowing the beans down as much as possible before they reached the fan opening, which led to the design being completely rebuilt.

10.2 - Trial 1, Dropping from top of the fan opening

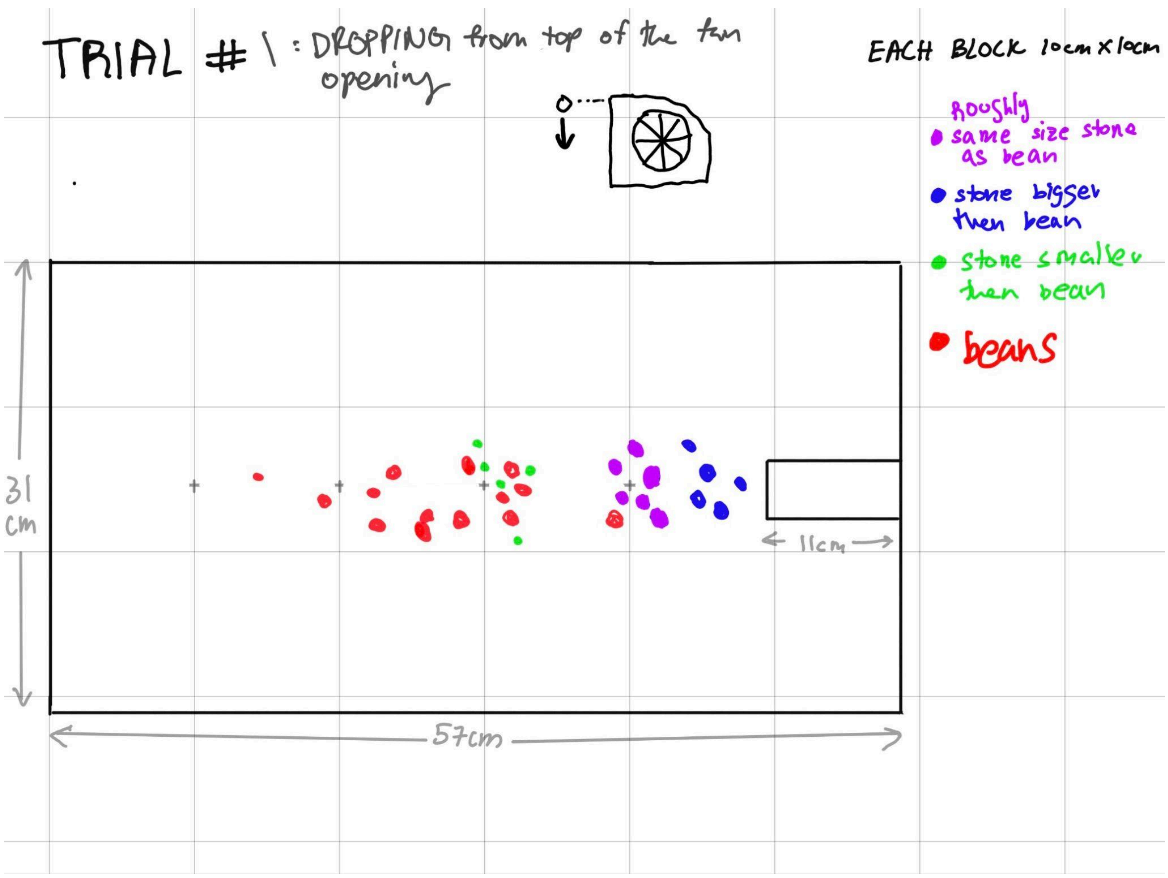


Figure 10.4 - Trial 1 dropping from the top if the fan opening results

Since it became clear early on that free-fall beans would never work, the first instinct was to drop the beans directly at the fan opening to see how they would react with minimal speed in front of the fan. As shown in the results above, the majority of the beans are falling roughly 5–10 cm away, similar to the beans that are relatively the same size as the stones or larger. However, stones that are smaller than the beans are falling roughly in the same range. This first trial made one thing clear: free-fall beans would not work, and the design should focus on ensuring the beans reach the fan opening with as little speed as possible. This would help overcome other forces and allow the beans to launch past the wall.

Figure 10.5 - Updated Setup With Wood

Figure 10.5 shows the setup built using a shoebox and wood for the outer walls. The base is labeled with different lengths to track where the beans and stones are landing, and the fan is placed roughly 14.5 cm from the surface.

10.3 - Trial 2 Ramp on top of Fan

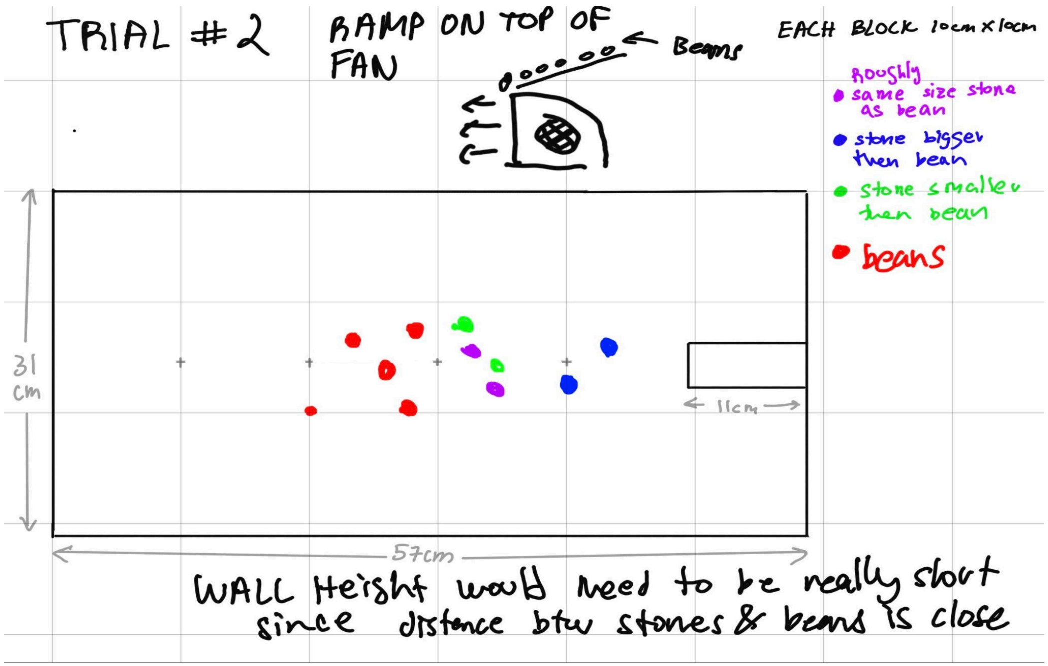


Figure 10.6 - Trial 2 ramp on top of fan results

The second trial was conducted by attaching a declining ramp on top of the fan, allowing the beans to exit the ramp and be hit by the airflow from the fan opening. The ramp was angled at roughly 15 degrees to ensure that the beans were not coming down too fast. As the results show, the beans tended to fall roughly 5 cm away from the stones. Although this trial was successful, there was a clear distance difference between the beans and the stones (roughly 5 cm). A potential issue that could arise in the future is that the difference between where the stones and beans are landing may not be large enough to create a reasonable height for the separation wall. This issue was addressed by using an inclined barrel attached to the fan opening to launch the beans and stones as a projectile. This is discussed in more detail in Trial #3.

10.4 - Trial 3 projectile launch using barrel with a top opening for bean/stone insert

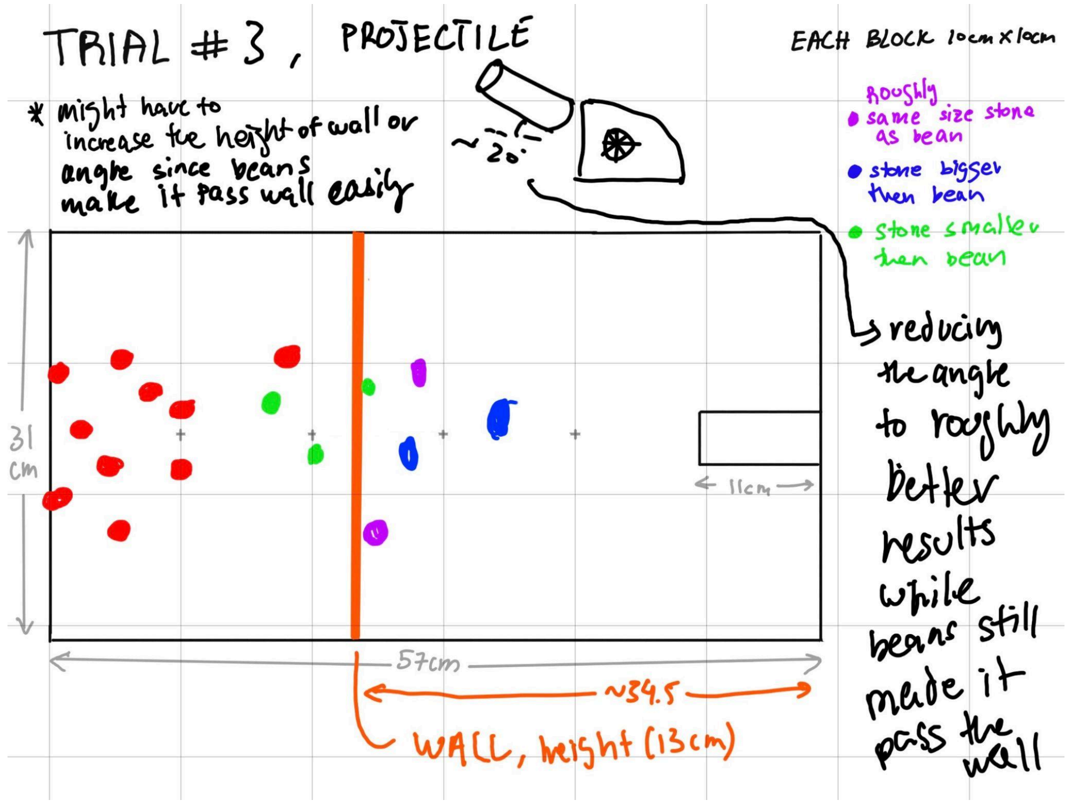


Figure 10.7 - Trial 3 Projectile Launch Using Barrel Results

For trial #3, a barrel was used at 20 degrees with a top opening to allow beans and stones to be inserted, and a wall was added to separate the stones from the beans. As the results show, the stones that are the same size as the beans or bigger did not make it past the wall. However, stones smaller than the beans easily made it past the wall. Reducing the angle of the projectile gave better results, and increasing it made it difficult for the beans to make it past the wall. This trial was successful as well, and the next step was to attach the barrel to something to allow a bunch of beans to flow at once towards the barrel opening, which was to attach a ramp similar to Trial #2 and connect it to the barrel opening. However, there was an issue with this, as the ramp opening did not perfectly align with the barrel opening, and very often the beans would enter the barrel opening and slip out. Additionally, the barrel is open from the back for airflow, and when a pile of beans made its way down to the barrel opening, some beans would escape through the back. This issue was fixed using mesh around the fan opening.

Figure 10.8 - Barrel made from foam cup

Figure 10.9 - Ramp attached to barrel

10.5 - Combining The Ideas 3 Trials & Issues Faced

After running three trials, the things that worked were all taken into consideration: the declining ramp and the barrel. However, the barrel was later changed to an inclined ramp, as shown in the pictures below. This change was necessary since it was difficult for the beans to enter the barrel opening. Also, during the test trial, many beans kept hitting the top of the enclosure, which resulted in beans scattering all over the place. Additionally, covering 60 percent of the fan from the bottom caused the fan to have stronger force, as all the air was redirected to the unblocked opening portion. To make the design modular, the height of the base where the fan is sitting was reduced, and the Spartan wall was brought closer to the design, resulting in a decrease in the overall length and height of the design.

Figure 10.10 - Built Prototype After trial 3

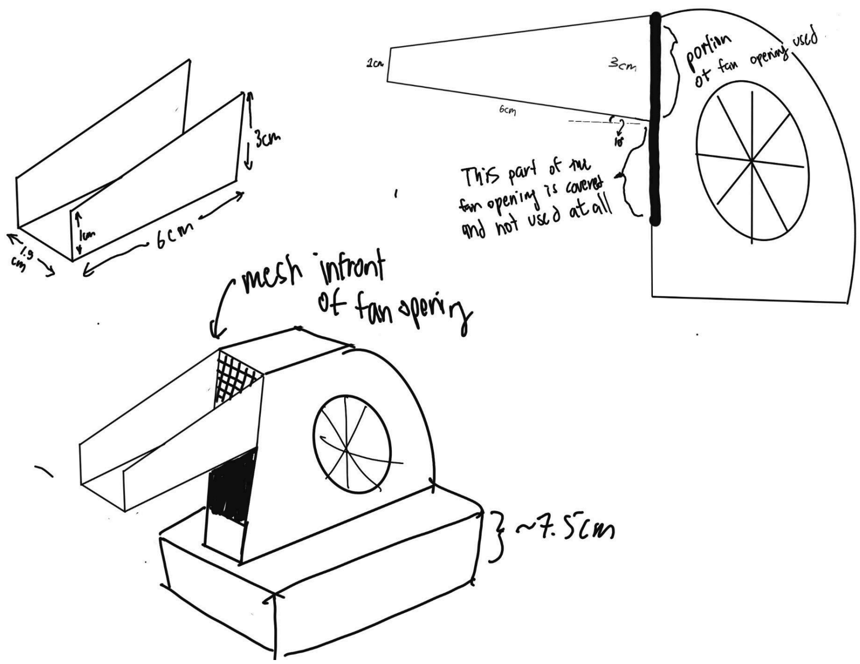


Figure 10.11 - Drawing of Small Ramp & Attachment to Fan

Some of the issues faced during prototyping were the beans clogging up in the declined ramp. Beans would often get stuck near the edges of the wall, this was likely due to the cardboard walls getting tilted, as well as the hot glue along the walls and the ground of the ramp. There was also clogging in the triangular funnel which was fixed by using a cone-shaped funnel. As for the clogging in the ramp, it was resolved by 3D printing the ramp which reduced the friction. Additionally, the inside edges of the ramp had fillets and the sharp corners were removed to make sure nothing gets stuck along the edges.

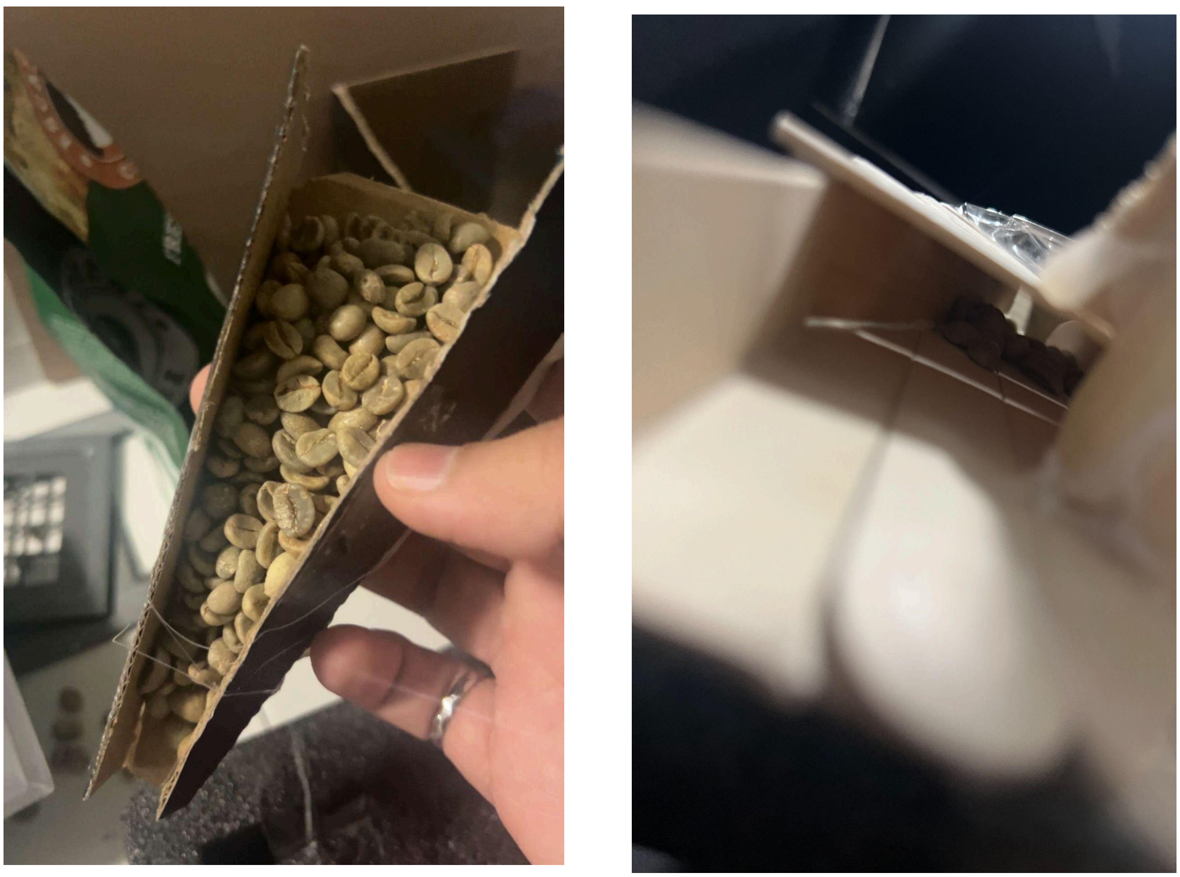


Figure 10.12 - Beans Clogged Inside Ramp at 45 Degrees, Edges, and Ramp Opening

Chapter 11 - Final Design

The final design integrates all the successful elements of the prototyping and testing stage from the second design implementation, which proved to be essential after the failure of the initial design, as the first design had relied only on simulations, which were not accurate, and had included no prototyping or testing.The final design is founded on the two-ramp mechanism for the deceleration of the beans and positioning them ahead of the fan outlet for efficient separation. The operation helps ensure that the beans are decelerated to the desired speed, allowing fan air to push them over the wall that separates beans and stones. The construction is fully encased, neat and professional appearance, and design inspiration from coffee makers and kitchen appliances, in compliance with color schemes of coffee for visual compatibility. All parts were 3D printed using PLA+ and assembled together with precision fit to support modularity and assembly convenience. A series of tolerance checks was carried out along the build sequence to allow unobstructed part mating and prevent even tiny gaps for compromising performance or aesthetics.Highlights of the modifications included rounding off the sharp edges, incorporating fillets on the inside of the ramps to prevent clogging by beans, and offering mesh in front of the fan inlet to hinder beans from reversing into the system. Modularity in the construction was also realized by halving the structure into a number of pieces to enable room for the building volume of the printer without compromising in creating a very solid final construction. The orientation of the fans and ramp angles were determined by trial and error with utmost precaution to ensure effective separation of beans and stones. Additional focus was directed toward the external finish to maintain visual attractiveness and conformity with kitchen appliance standards. Combined with simplicity of use, the design is easy to clean and maintainable, thus making it convenient for regular use. The final product is a destoner with an ideal balance between performance, aesthetics, and ease of use. The prototype is successful in bringing all of the lessons learned through each trial into a clean, compact, and elegant design.

Figure 11.1 - Final design illustration

Chapter 12 - 3D Printing

The entire design was printed using 3D printing. The PLA+ filament was selected for the strength and flexibility properties it offered, making it suitable for both structural components and parts exposed to impact from the beans. The outer walls were printed at 0.5 cm thickness. For those parts under minimal load, an infill rate of approximately 15% was utilized, and for those parts exposed to constant load from the beans and stones, a 30% infill was utilized. Triangular and lightning infill patterns were the most prevalent infill patterns utilized, as they possess a great strength-to-weight ratio and are structurally adequate to give structural integrity when loaded without using too much print time. All prints used a 0.4 mm nozzle and 0.3 mm layer thickness at a print speed of 300 mm/s. Due to the limited build volume available, which was only 220 x 220 x 220 mm, the outer structure had to be split into various parts. There was extensive use of support material to ensure print stability as well as to prevent failures, especially for complex parts. Approximately 3 kg of filament was used, and the whole print process lasted for approximately 25–30 hours.Post-processing consisted of sanding all the parts, especially the outer walls, with sandpaper of 220 to 400 grit for PLA+, and finally finishing them using special metallic spray paint in order to shape the prototype into a kitchen appliance. Pieces that were going to be glued together were attached together with Gorilla Glue. One of the issues the multi-piece design created was that the alignment during assembly was critical. There were many tolerance tests run to make sure all the pieces would fit together perfectly with no misalignment or gaps, which was not only important for the structural integrity but also for the looks of the final product.

Figure 12.1 - Tolerance test print

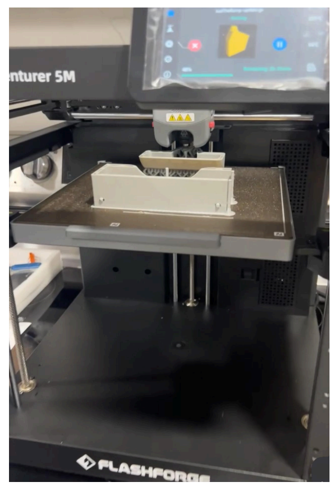


Figure 12.2 - 3D printing ramp

Chapter 13 - Conclusion/Final Remarks

Coffee bean destoning is an integral part of the at home coffee roasting process and can be frustrating to many roasters. Stones that make it through the destoning process can damage coffee grinding equipment and jeopardize the final product. Through the implementation of a coffee bean destoner such as this prototype the at home roasting process can be saved. Many coffee bean destoners on the market are made for industrial sized batches and are too large and expensive for many at home coffee enthusiasts. The goal of the design of this prototype was to design a coffee bean destoner that easily fits in your kitchen as a countertop appliance like a coffee machine, a toaster or microwave. The goal is to have a functional coffee bean destoner that is not much louder than your coffee grinder that can be stored away after use. The simple yet effective solution to this problem is the fan based system that our prototype implements that allows for the separation of stones from the coffee beans based on their density. The compact fan system is much quieter and allows the product to be much more portable than almost anything on the market. Keeping the system simple allows for an intuitive user experience while ensuring the long term reliability of the destoner. There were many design iterations that allowed the team to learn what works and what needs to be changed to ensure the functionality of the product. Extensive testing took place from mathematical modelling, CFD analysis and prototyping to ensure the chosen design is as effective as possible. Various materials were considered but PLA was chosen because it is cost effective, durable, and food safe. The fan speed is controlled with the use of an arduino which allows the team to optimize the flow rate to maximize the number of beans that make it into the coffee tray without ending up in the waste tray. The prototype is an effective destoner that was able to maximize its capability while minimizing its cost and size making it a great choice for consumers.

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Appendix A - Electrical Tables

Table A.1 Circuit components and connections

Component	Connection 1	Connection 2
12V Adapter	Y-Splitter	Arduino barrel jack & terminal block
Fan + (red)	Terminal block +12V	
Fan – (black)	MOSFET Drain	
MOSFET Source	Terminal block GND	
MOSFET Gate	Arduino D3	10kΩ pull-down to GND
10kΩ Resistor	MOSFET Gate	GND
Flyback Diode	Cathode: Fan + / +12V	Anode: Fan – / Drain
Start Button	D4	GND
Stop Button	D5	GND
Arduino GND	Terminal block GND	Breadboard GND rail

Table A.2 Circuit Components and Quantities

Component	Quantity
12V, 5A AC/DC Wall Adapter	1
Y-Splitter Jack (1-to-2)	1
IRLZ544N N-Channel MOSFET	1
1N5818 Flyback Diode	1

10kΩ Resistor	1
Push Buttons	2
Arduino Uno R3 Microcontroller	1
12V DC Centrifugal Blower Fan	1
Breadboard	1
Barrel Jack to 2-Pin Screw Terminal Block	1
Jumper Wires	15

Appendix B - Programming

```
// Pin Definitions
const int fanPin = 3;       // Pin connected to the MOSFET Gate
const int startButton = 4;  // Start button connected to Pin 4
const int stopButton = 5;   // Stop button connected to Pin 5

int fanSpeed = 20;         // Maximum fan speed (0-255 for PWM)
bool fanRunning = false;    // Track whether the fan is on or off

void setup() {
  // Set pin modes
  pinMode(fanPin, OUTPUT);
  pinMode(startButton, INPUT_PULLUP);
  pinMode(stopButton, INPUT_PULLUP);
}

void loop() {
  // Check if the Start button is pressed
  if (digitalRead(startButton) == LOW) {
    fanRunning = true;
  }

  // Check if the Stop button is pressed
  if (digitalRead(stopButton) == LOW) {
    fanRunning = false;
  }

  // Control the fan based on the fanRunning state
  if (fanRunning) {
    analogWrite(fanPin, fanSpeed); // Turn on fan at full speed
  } else {
```

```
    analogWrite(fanPin, 0); // Turn off the fan
  }
}
```

Appendix C - Preliminary Design Calculations

Step 1:

Region 1:

Given $a = 9.81 m/s^2,\ h = 0.05 m,\ v_1 = 0$ determine the velocity of the bean as it exits region 1.

$v_2^2 = v_1^2 + 2ah$

$v_2 = \sqrt{2ah} = \sqrt{2(9.81)(0.05)}$

$v_2 = 1 m/s$

Region 2:

y-component:

Given $v_{1y} = v_{1\,region\,1} = 1 m/s,\ a_y = 9.81 m/s^2,\ h_2 = 0.05 m$ determine the time that the beans and stones will remain in this region.

$h_2 = v_1 \Delta t + \frac{1}{2} a_y \Delta t^2$

$0.015 = 1\Delta t + \frac{1}{2} 9.81 \Delta t^2$

$\Delta t = 0.014 s$

x-component:

Given $v_{1x} = 0 m/s,\ x = 0.05 m,\ \Delta t = 0.014 s$ determine the acceleration in the x direction to provide enough force to move the beans.

$x = v_{1x} \Delta t + \frac{1}{2} a \Delta t^2$

$0.05 = \frac{1}{2} a_x (0.014)^2$

$a_x = 510.2 m/s^2$

Region 3: The height of the separation wall will be determined based on the overall height of the machine but the top of the wall will be 6.5cm from the funnel opening.

Step 2:

Drag Force:

Drag Force (F_D), Mass of Coffee Bean (m) and (a_x)

$$F_D = ma_x = (1.63 \times 10^{-4})(510.2)$$

$$F_D = 0.0832N$$

A drag coefficient of 0.46 based on *Aerodynamic properties of coffee cherries and beans* [5] due to the expected water content of 12.7 w.b% for a Catuai (arabica) bean.

Required Air Flow Velocity:

Drag Coefficient (C_D), Airflow Velocity (v_x) and density (ρ)

$$C_D = \frac{F_D}{\frac{1}{2}\rho v_x^{\ 2}A} => C_D = \frac{2F_D}{\rho v_x^{\ 2}A} => v_x = \sqrt{\frac{2F_D}{\rho C_D A}} = \sqrt{\frac{2F_D}{\rho C_D(\frac{2}{3}\pi abc)}}$$

$$v_x = \sqrt{\frac{2(0.0832)}{785(0.46)(\frac{2}{3}\pi(0.01)(0.004)(0.007))}}$$

$$v_x = 28.032m/s$$

Reynold’s Number of the airflow in the vent:

Reynolds Number (Re), Vent Length (L) and Kinematic Viscosity (υ)

$$Re = \frac{v_x L}{\upsilon} = \frac{28.032\times0.01}{1.6\times10^{-5}}$$

$$Re = 17,520$$

Based on these parameters a PC fan was chosen, the model that was chosen was the Noctua NF-P14 redux 1500 PWM. This model provided a mass airflow (Q) of $120.2m^3/h$ with a diameter of 140mm, and a maximum speed of 1500rpm.

$Q = 133.7 m^3/hr = 0.037139 m^3/s$

$A_1 = 0.14 \times 0.14 = 0.0196 m^2$

ρ_{air} at @20℃ $= 1.2041 m^3/s$

Inlet Velocity:

Inlet Velocity (v_1),and Inlet Cross Sectional Area (A_1)

$v_1 = \frac{Q}{A_1} = \frac{0.037139}{0.0196} = 1.89 m/s$

Outlet Velocity:

Outlet Velocity (v_x), Outlet Cross Sectional Area (A_2), Vent Outlet Height (h) and Vent Outlet Width (w)

$v_1 A_1 = v_x A_2 => v_1 A_1 = v_x (h \times w)$

$w = \frac{1.89 \times 0.0196}{28.032 \times 0.015}$

$w = 0.08809 m$

Appendix D - Preliminary CFD

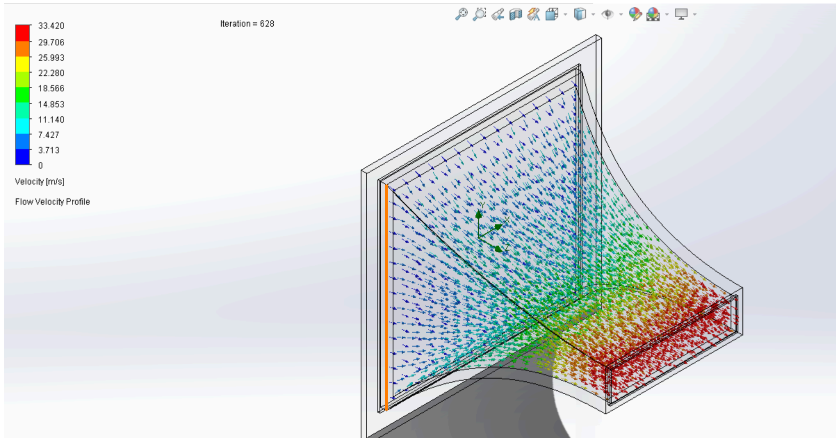


Figure D.1 - Isometric View of the Duct Velocity Profile

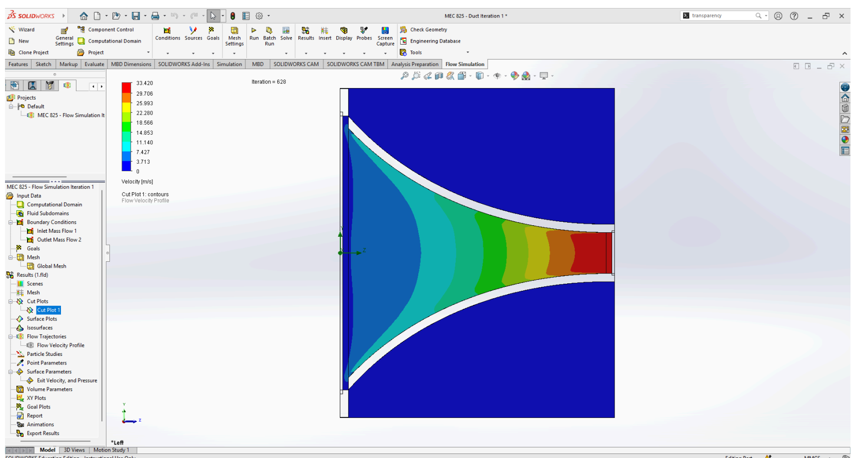


Figure D.2 - Side View of the Velocity Profile

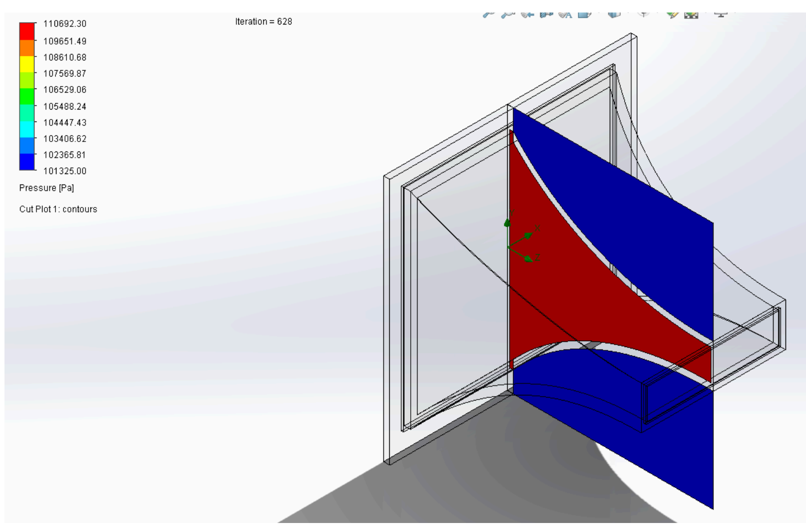


Figure D.3 - Isometric View of the Pressure Profile

Appendix E - Final Design CFD

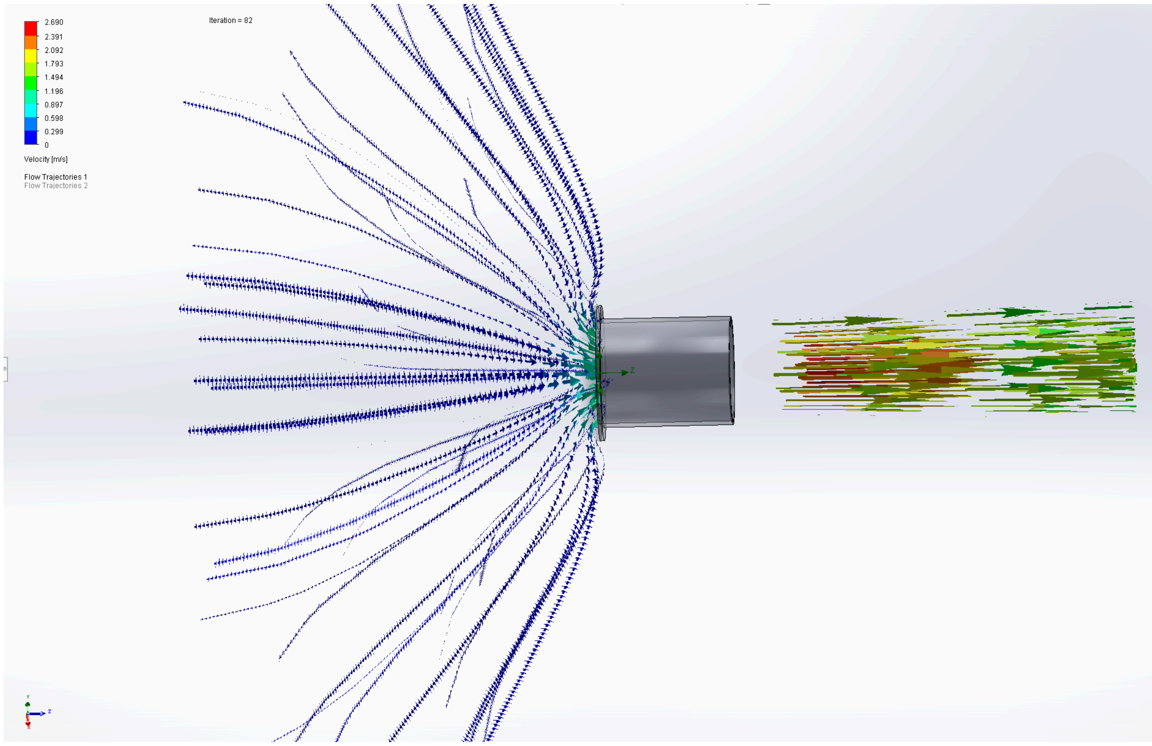


Figure E.1 - Intake Pipe Inlet and Outlet Velocity Vectors

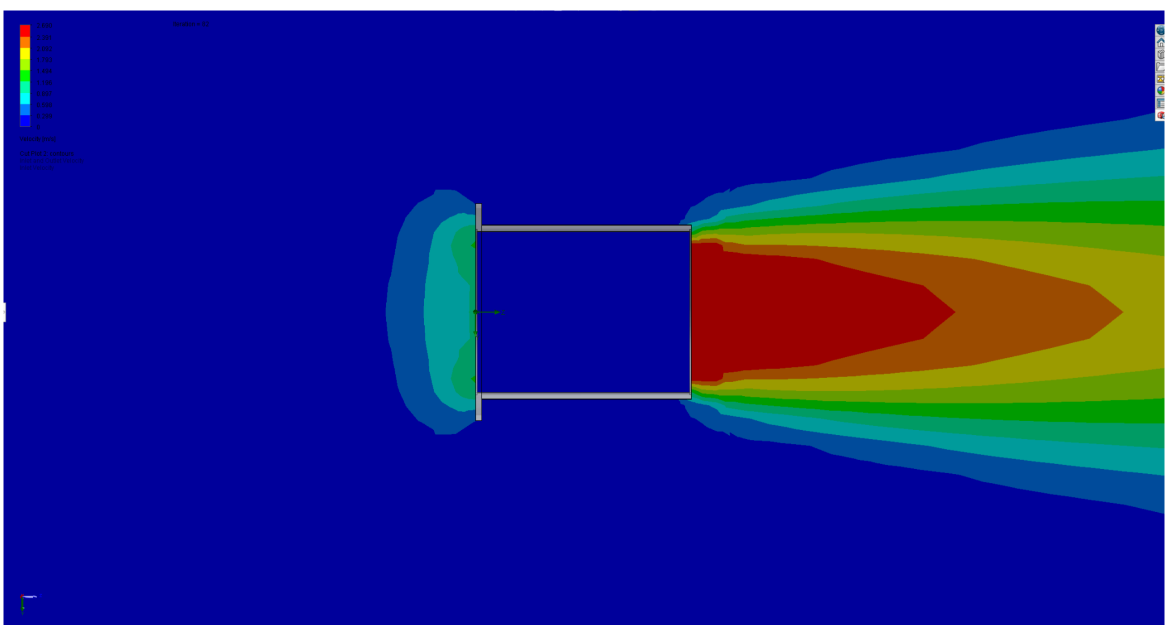


Figure E.2 - Intake Pipe Inlet and Outlet Velocity Profile

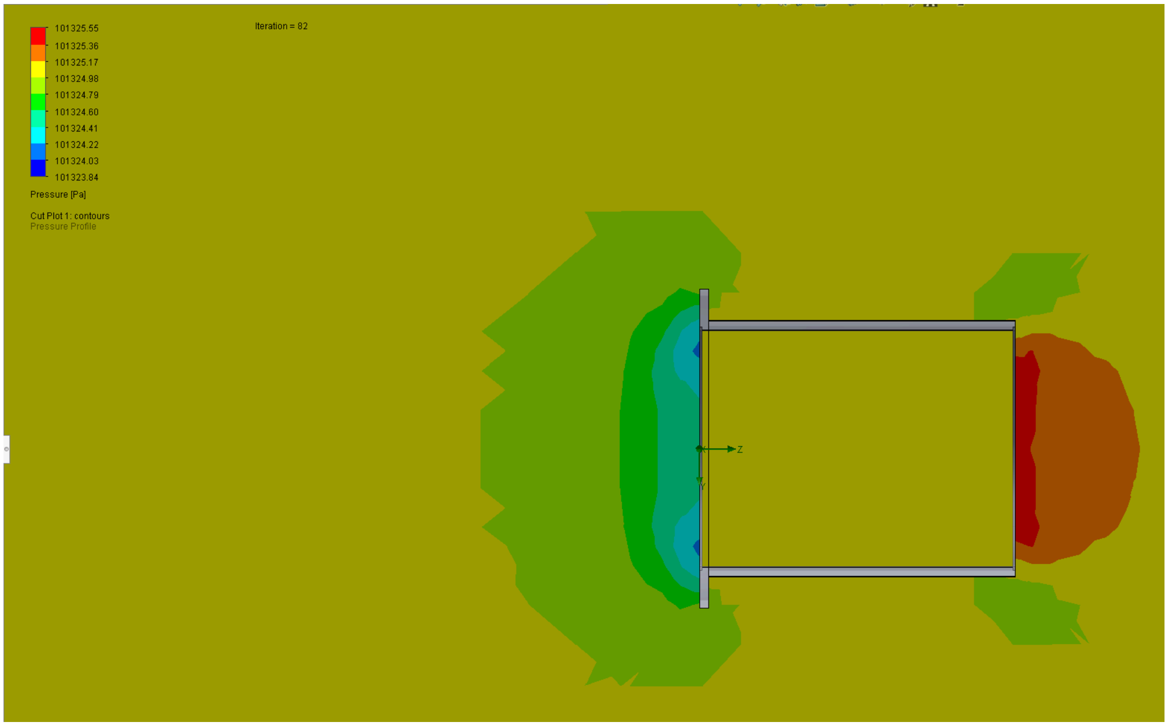


Figure E.3 - Intake Pipe Pressure Profile

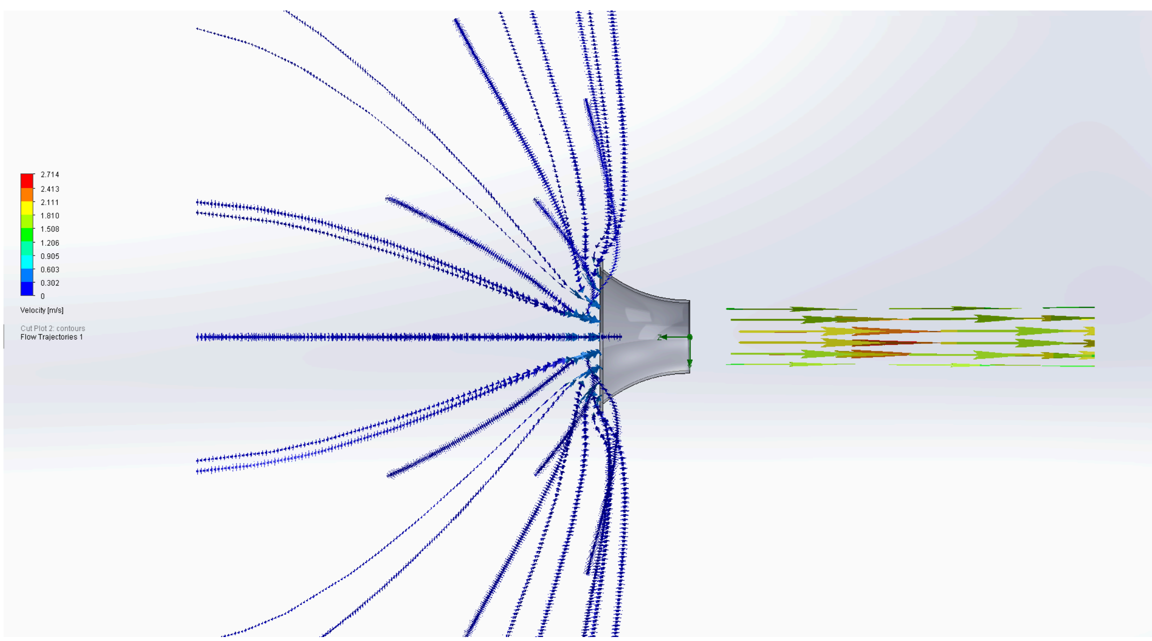


Figure E.4 - Intake Pipe Inlet and Outlet Velocity Vectors

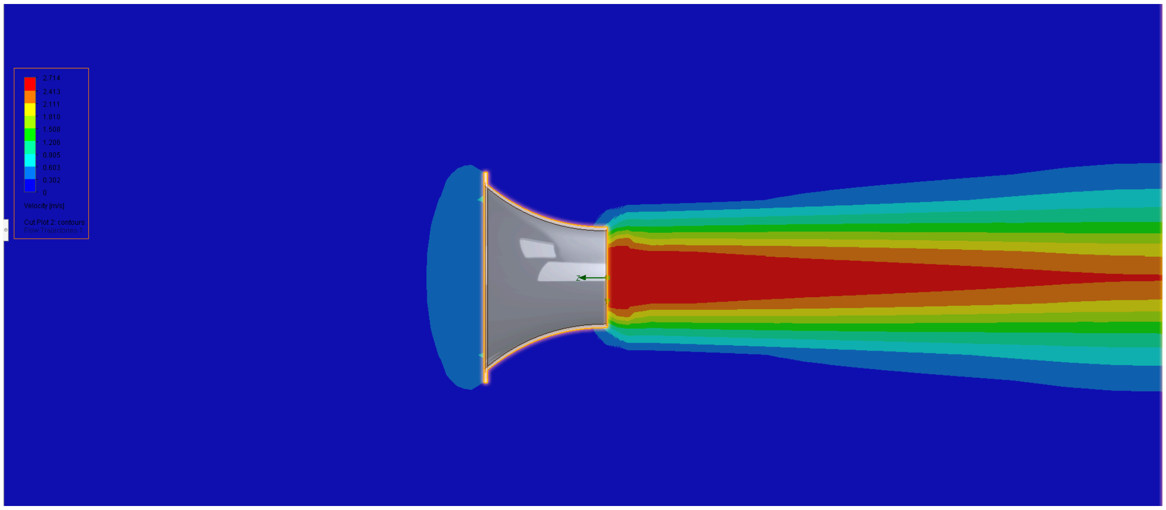


Figure E.5 - Intake Pipe Inlet and Outlet Velocity Profile

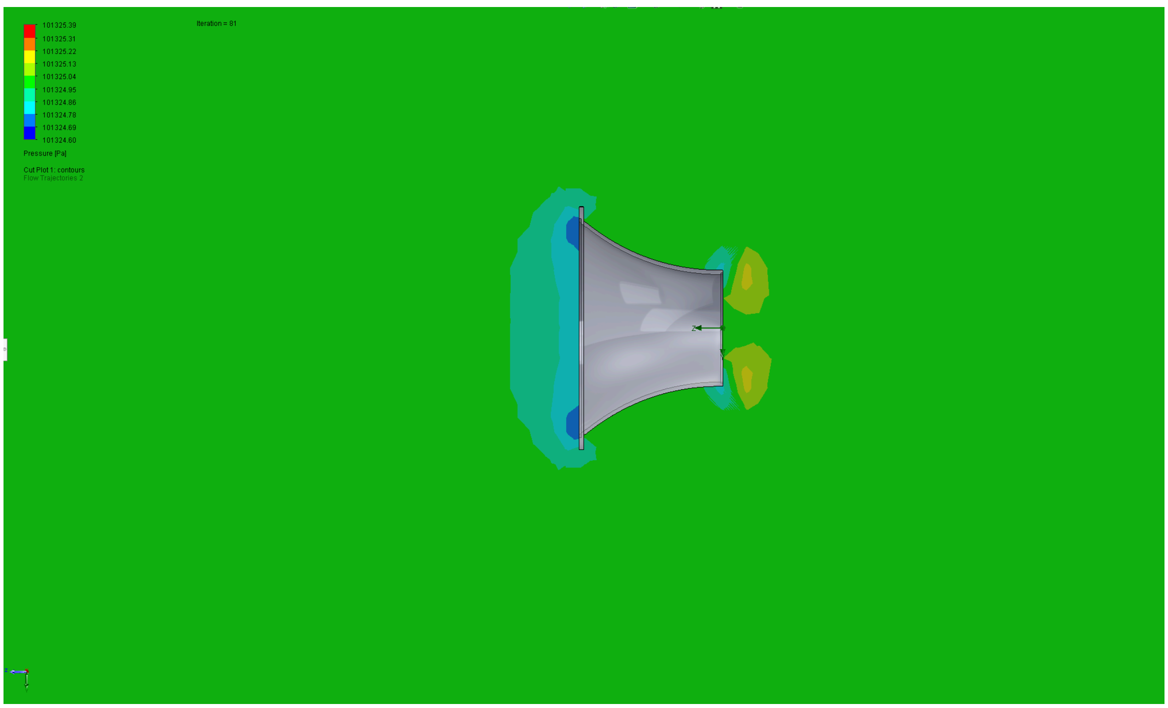


Figure E.6 - Intake Pipe Pressure Profile

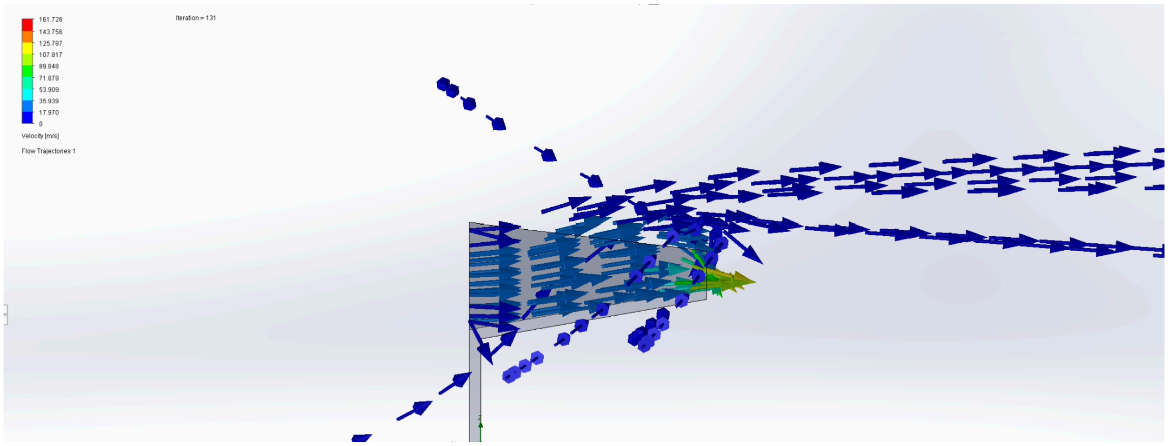


Figure E.7 - Ramp Velocity Vectors

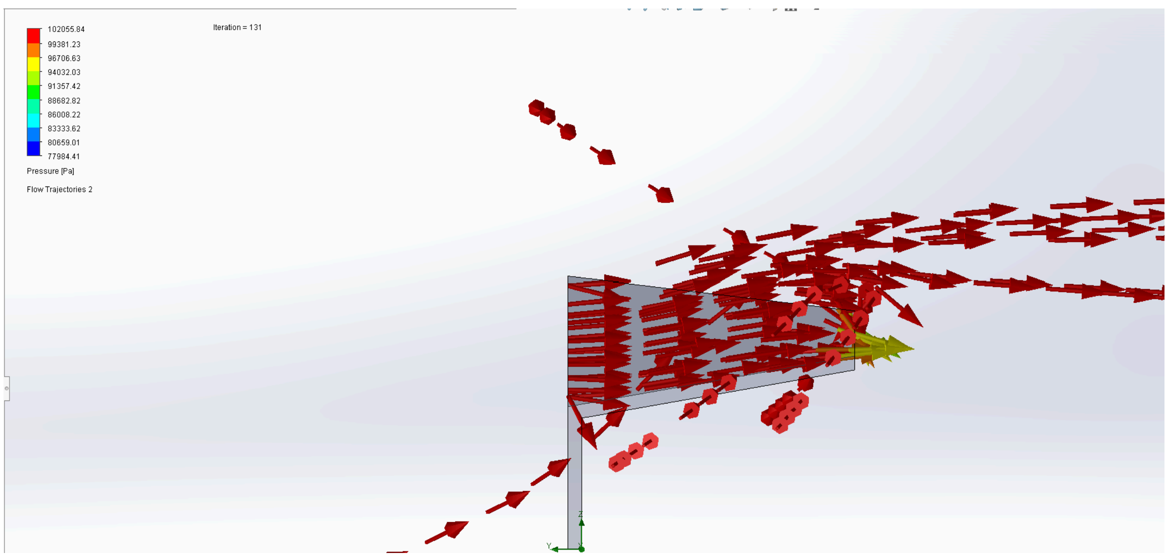


Figure E.8 - Ramp Pressure Profile

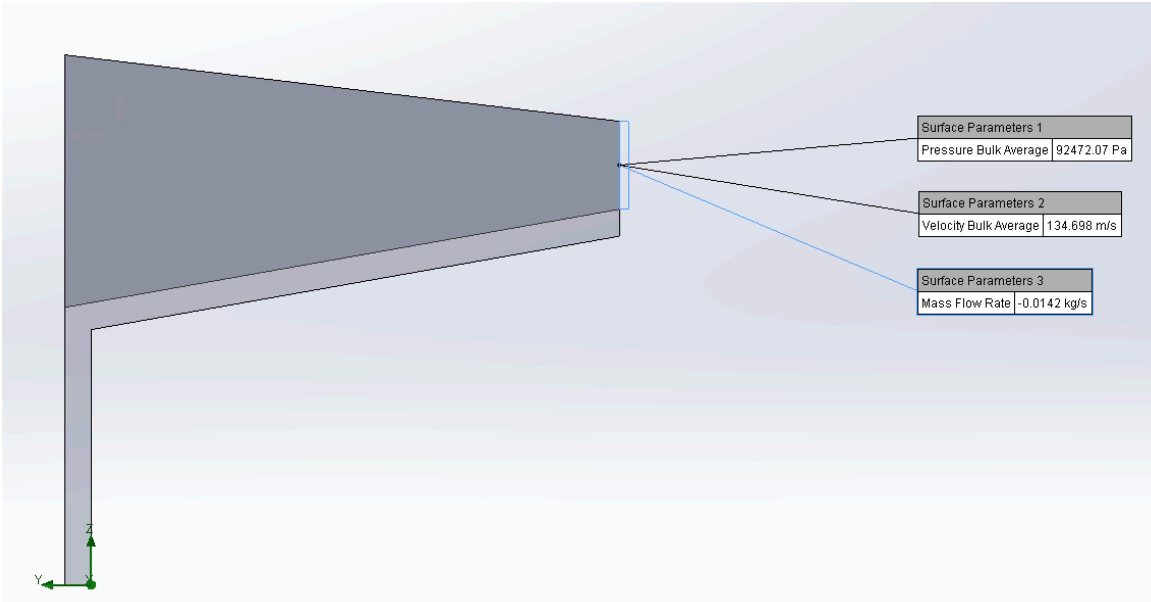


Figure E.9 - Ramp Outlet Parameters

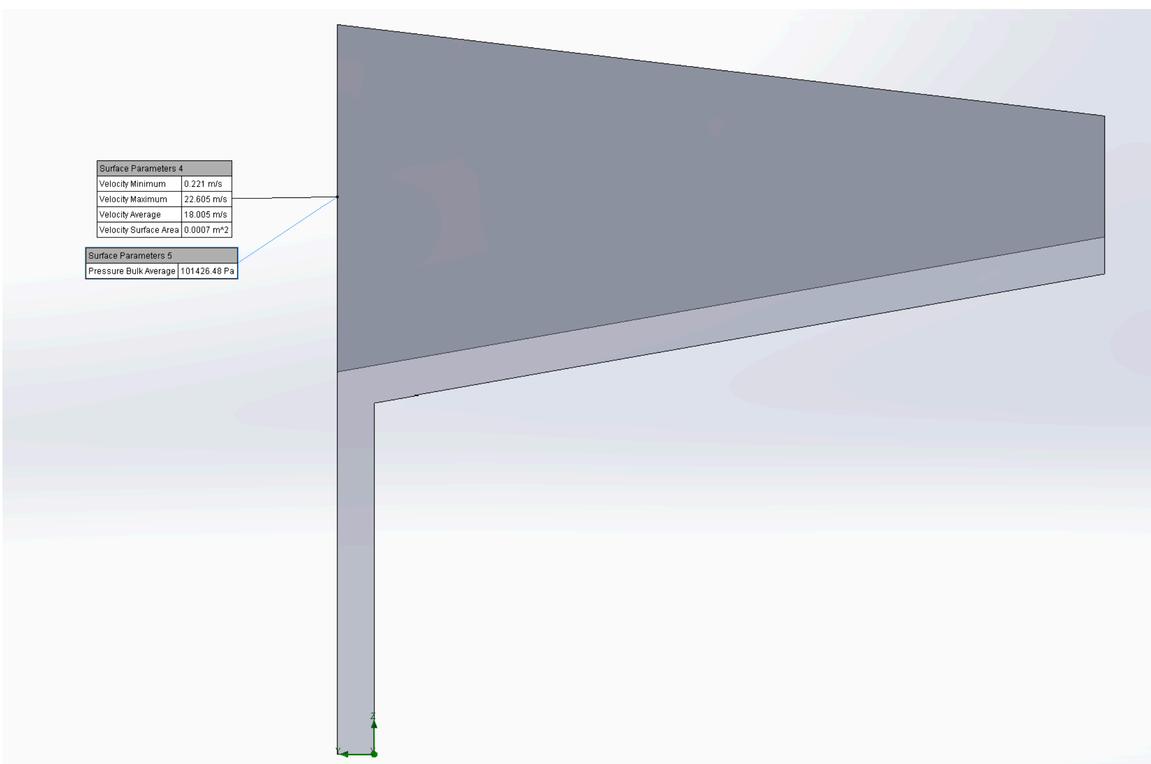


Figure E.10 - Ramp Inlet Parameters

Appendix F - Final Design Calculations

Table F.1 - Projectile Motion Calculations

Minimum Speed for Bean to pass/Maximum speed of stone to fail			
X-Direction		Y-Direction	
a	0	g	-9.81
v1x	1.091255623	v1y	0.1924178092
v2x	1.091255623	v2y	
x	0.12	y	-0.03815357437
t	0.099650691	t	0.1099650691
v	1.10809		

5.3 Ramp Acceleration Calculation

$$a = \frac{{v_2}^2}{2d} = \frac{1.10809^2}{2\times0.06397}$$

$$a = 0.03927 m/s^2$$

5.4 Drag Force of the Beans

$$F_D = ma = \rho V a = 785(\frac{2}{3}\pi(0.01)(0.004)(0.007))0.03927$$

$$F_D = 1.808 \times 10^{-5} N$$

5.5 Minimum Fan Airflow Velocity

$$C_D = \frac{F_d}{\frac{1}{2}\rho {v_{min}}^2 A} => v_{min} = \sqrt{\frac{2F_D}{\rho C_D A}} = \sqrt{\frac{2F_D}{\rho C_D (\frac{2}{3}\pi abc)}} = \sqrt{\frac{2(1.808\times10^{-5})}{785(0.46)(\frac{2}{3}\pi(0.01)(0.004)(0.007))}}$$

$$v_{min} = 0.4132 m/s$$

5.6 Drag Force of the Stones

$F_D = ma = \rho Va = 1680(\frac{2}{3}\pi(0.01)(0.004)(0.007))0.03927$

$F_D = 3.869 \times 10^{-5} N$

5.7 Maximum Fan Airflow Velocity

$C_D = \frac{F_d}{\frac{1}{2}\rho v_{max}^2 A} \Rightarrow v_{max} = \sqrt{\frac{2F_D}{\rho C_D A}} = \sqrt{\frac{2F_D}{\rho C_D(\frac{2}{3}\pi abc)}} = \sqrt{\frac{2(1.232\times10^{-5})}{1680(0.46)(\frac{2}{3}\pi(0.01)(0.004)(0.007))}}$

$v_{max} = 0.7324 m/s$

5.8 Fan Output Calculations at Maximum Speed

The maximum volumetric flow rate specified by the fan was 36.2CFM.

$Q = 36.2 CFM = 0.01708 m^3/s$

$v = \frac{Q}{A} = \frac{0.017084}{1.95\times10^{-3}}$

$v = 8.761 m/s$

5.9 Fan Output Speed Reduction

Fan Operation Speed: 0.7m/s

Maximum Fan Operating Speed: 8.761m/s

$\%Maximum\ Operating\ Speed = \frac{Fan\ Operating\ Speed}{Maximum\ Operating\ Speed} \times 100\% = \frac{0.7}{8.761} \times 100\%$

$\%Maximum\ Operating\ Speed = 8.000\%$

5.10 Coded Fan Speed

$Coded\ Speed = 255 \times 8.000$

$Coded\ Speed = 20.4$ round down to the nearest whole number $Coded\ Speed = 20$

Appendix G - Final Design Engineering Drawings

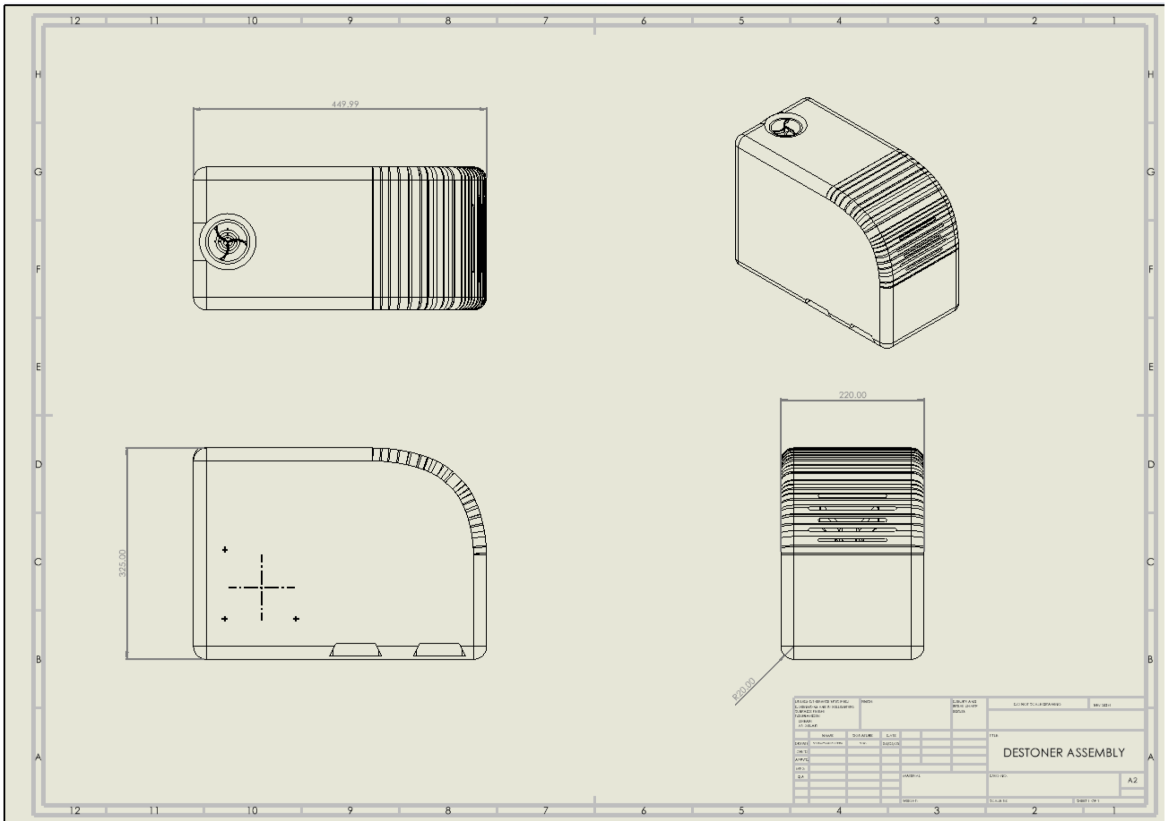


Figure G.1 Destoner Assembly Drawing

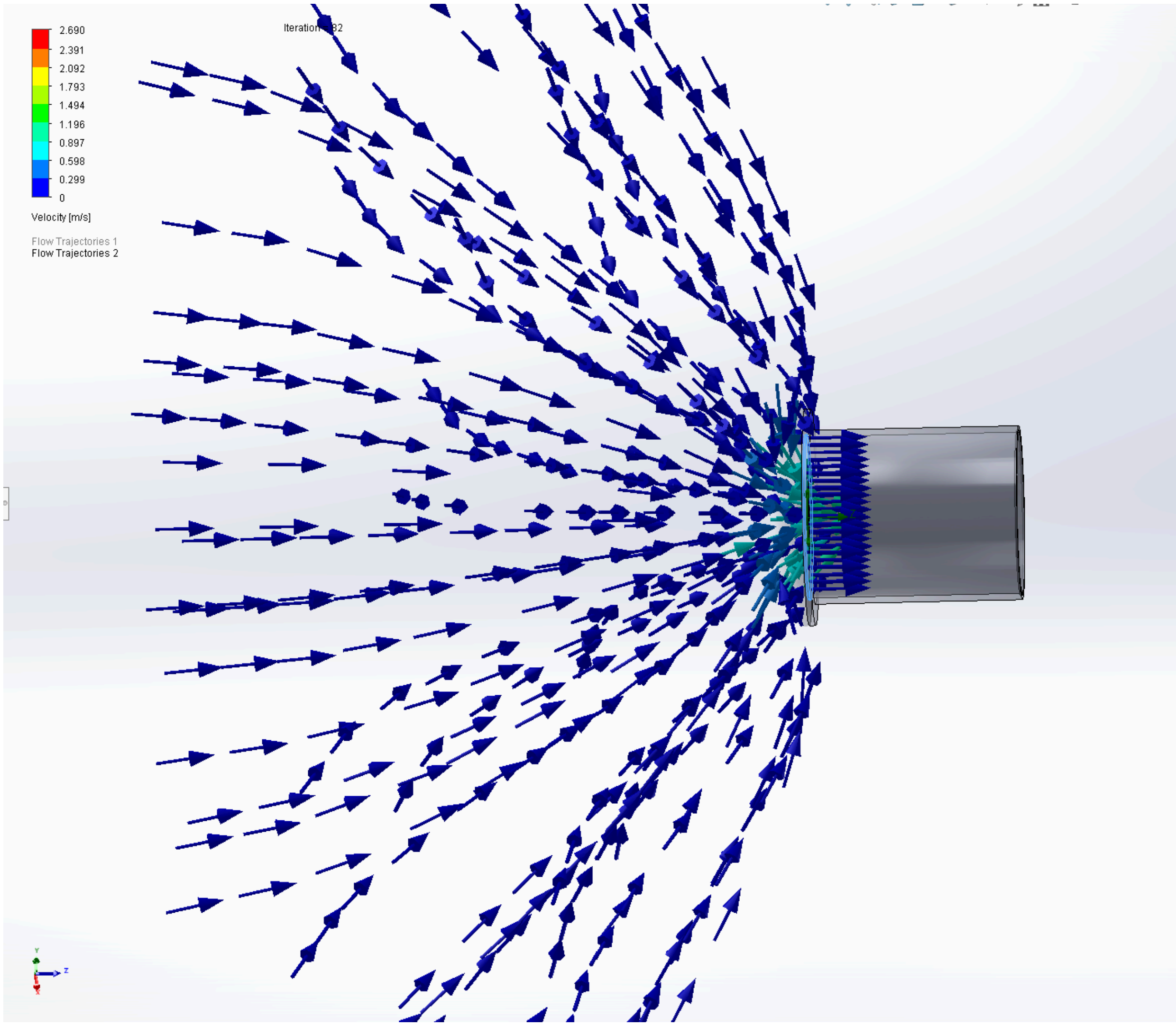
Appendix H - CAD & Design Illustrations

Figure H.1 CAD Model of Prototype

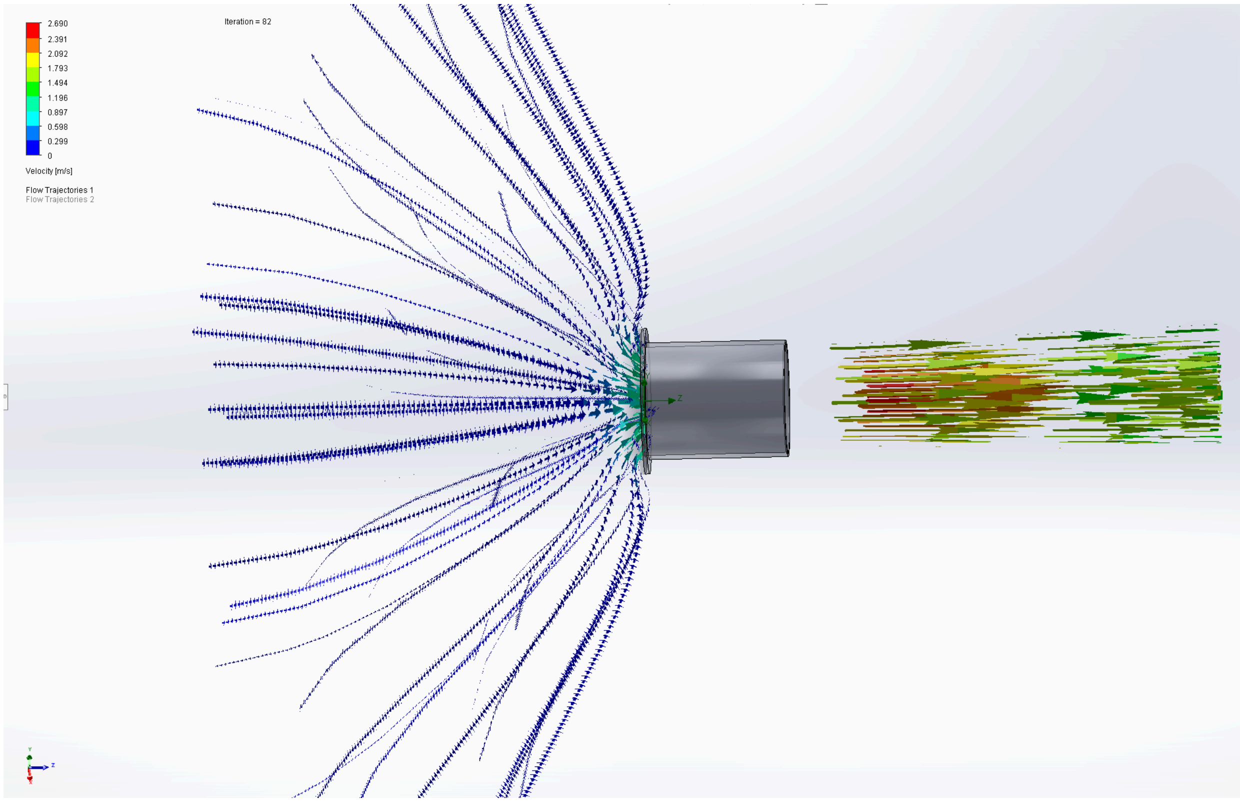
Figure H.2 CAD Model of Prototype

Figure H.3 Design Illustration of Prototype

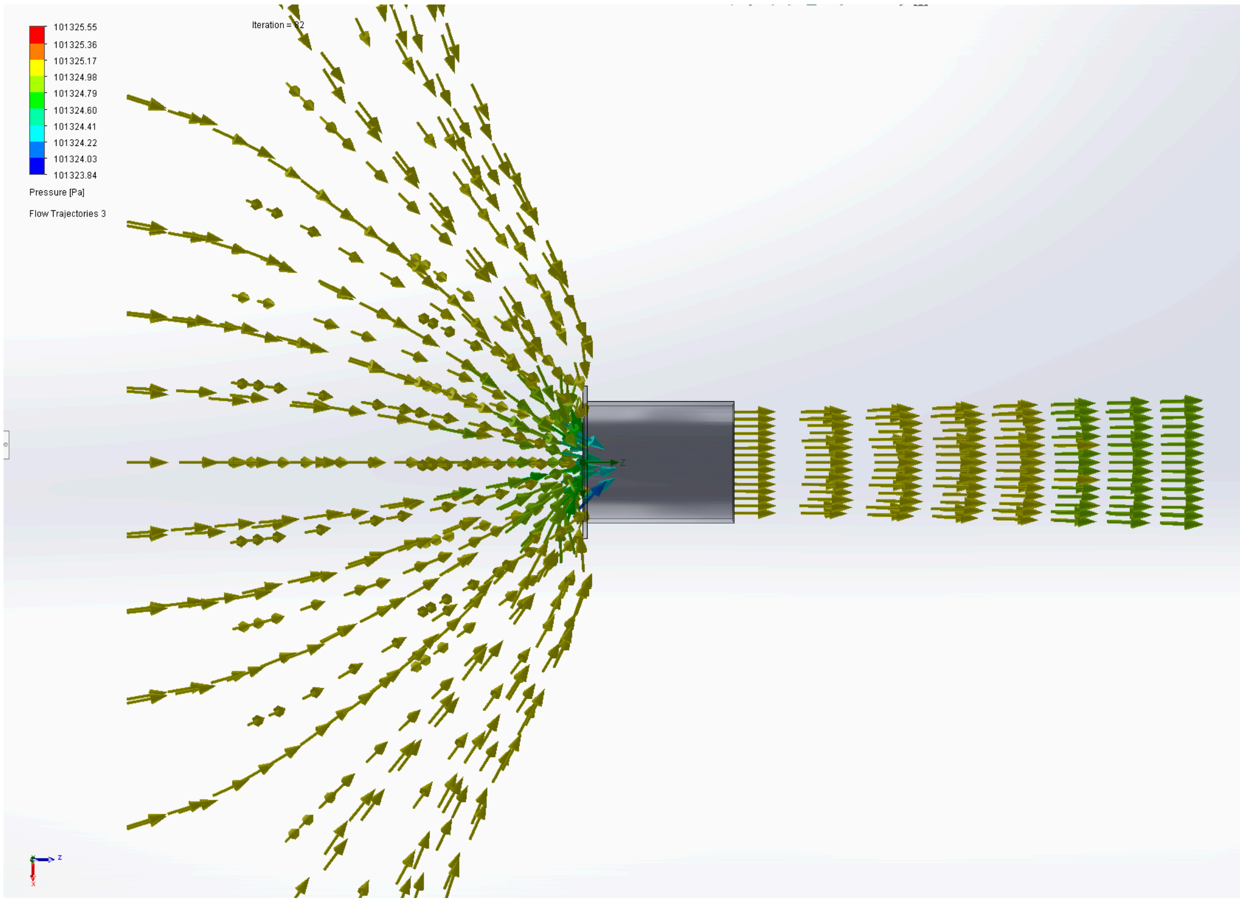
Design Iteration 2



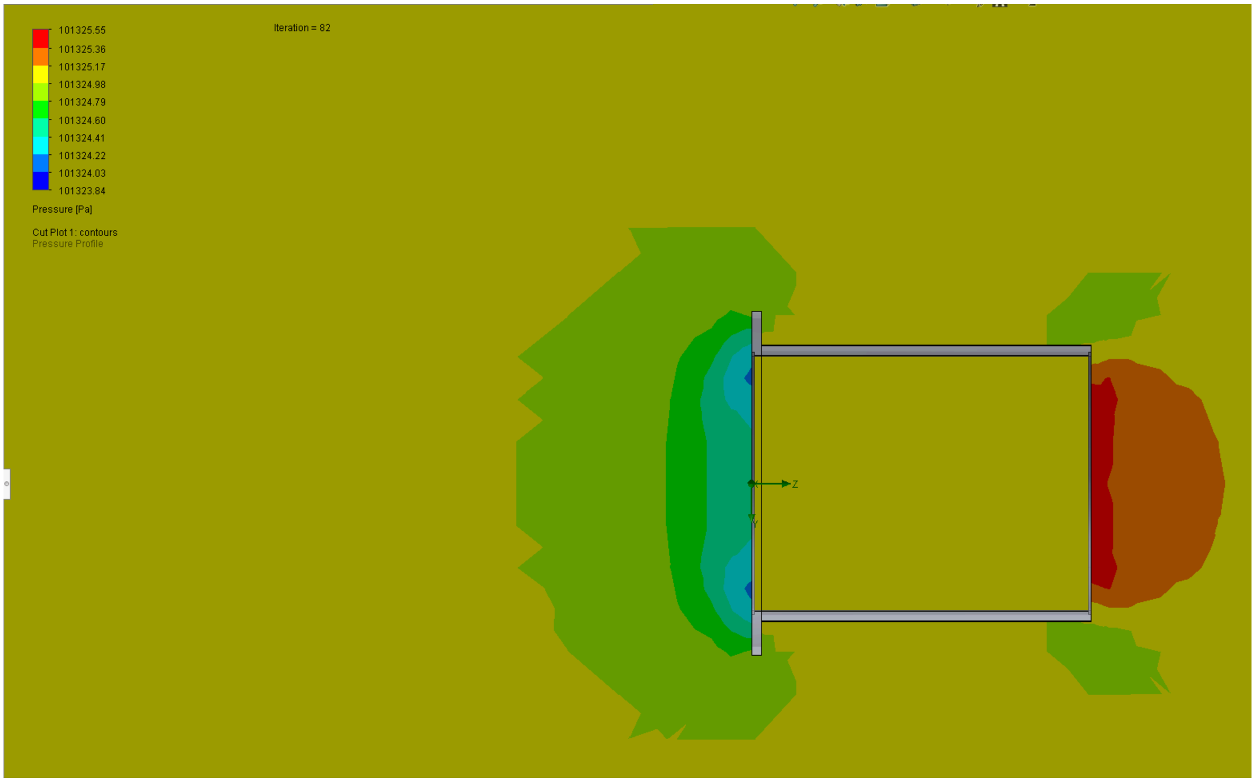
Inlet Velocity



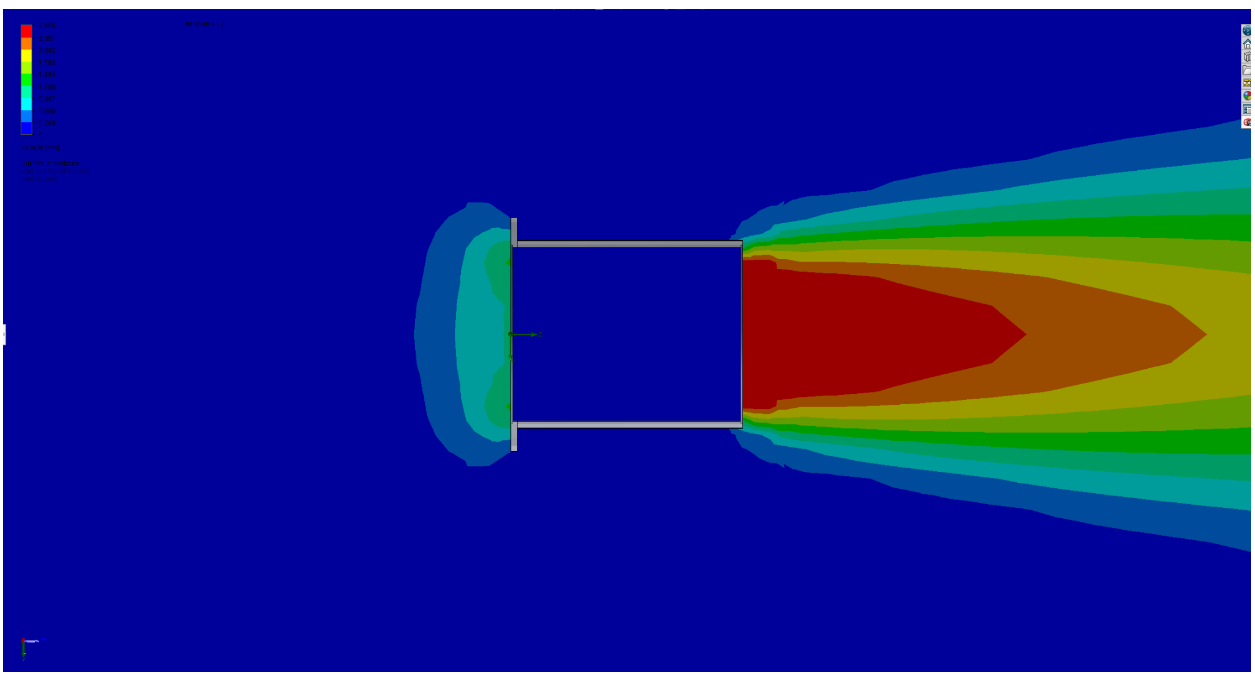
Inlet and Outlet Velocity



Pressure Profile

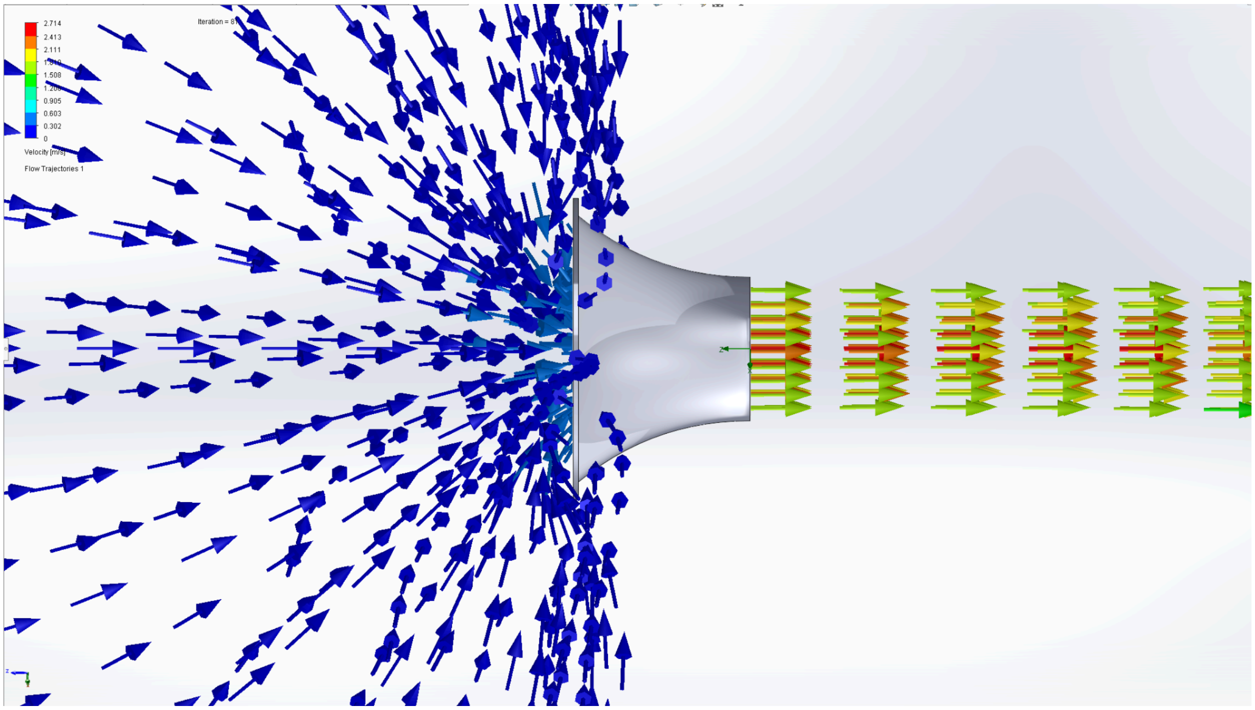


Internal and External Pressure Profiles

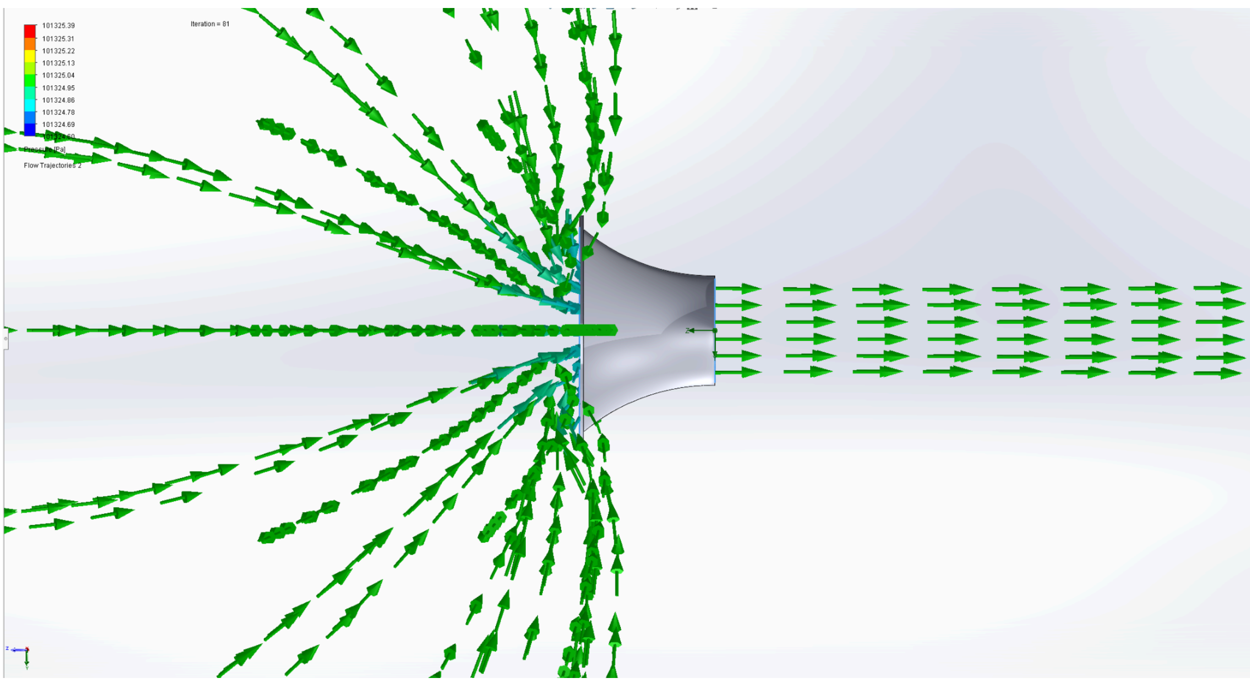


Velocity Profile

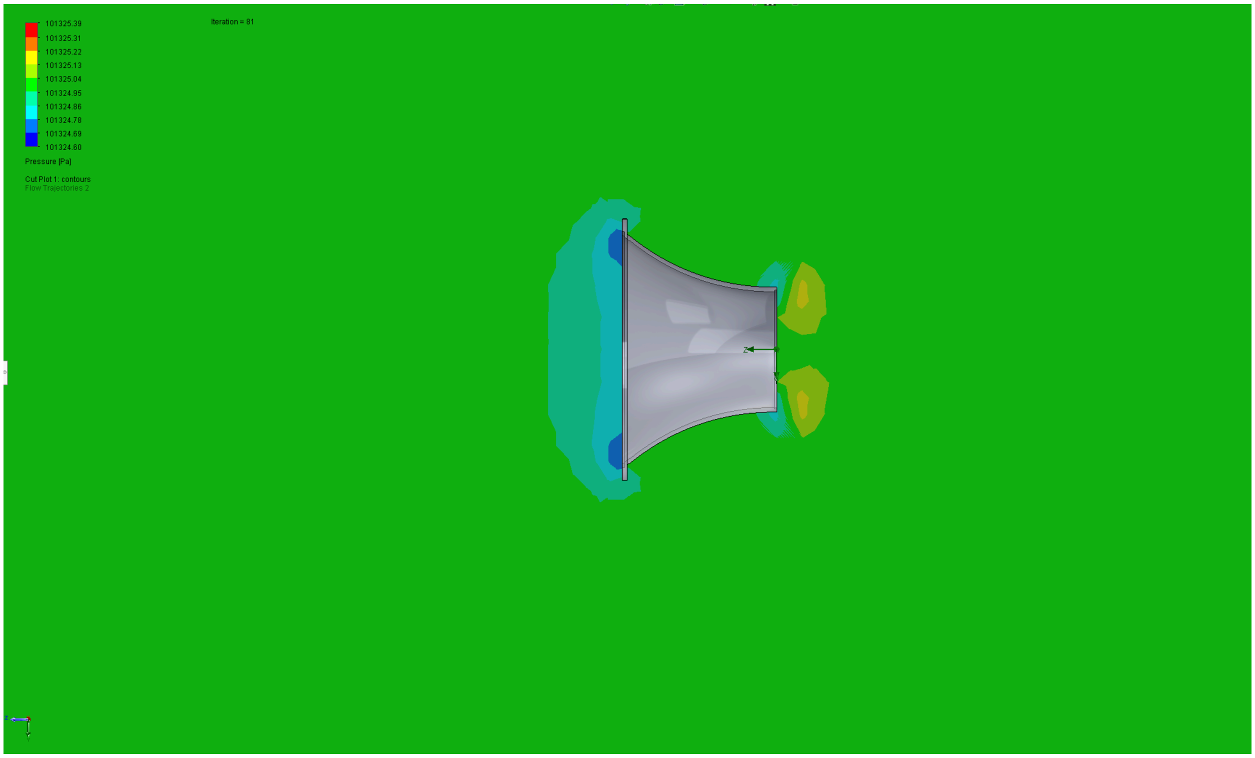
Iteration 3:



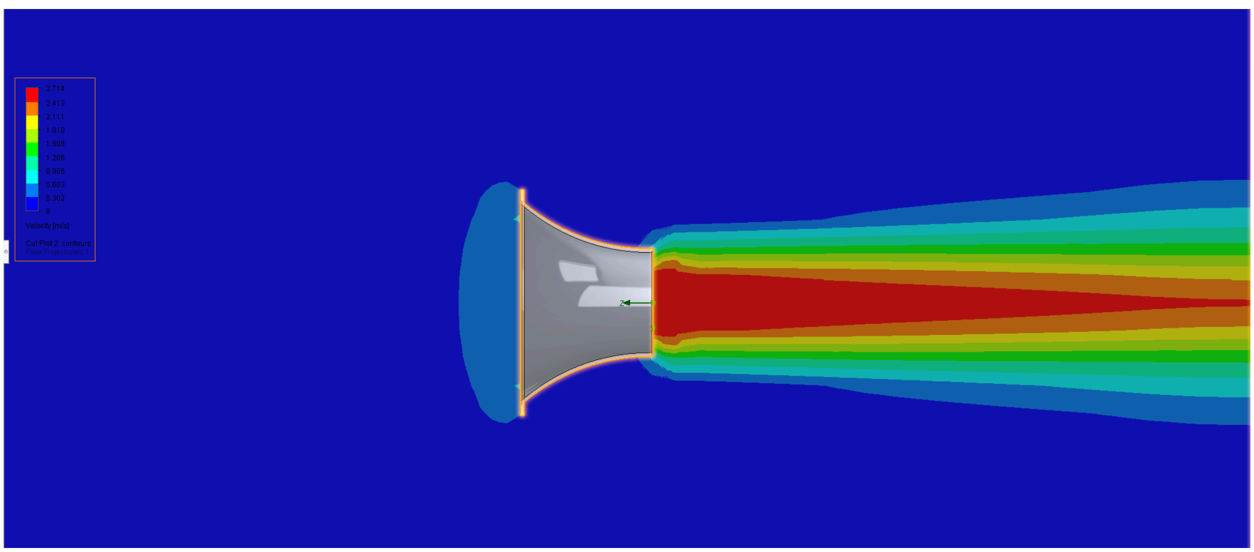
Velocity Profile



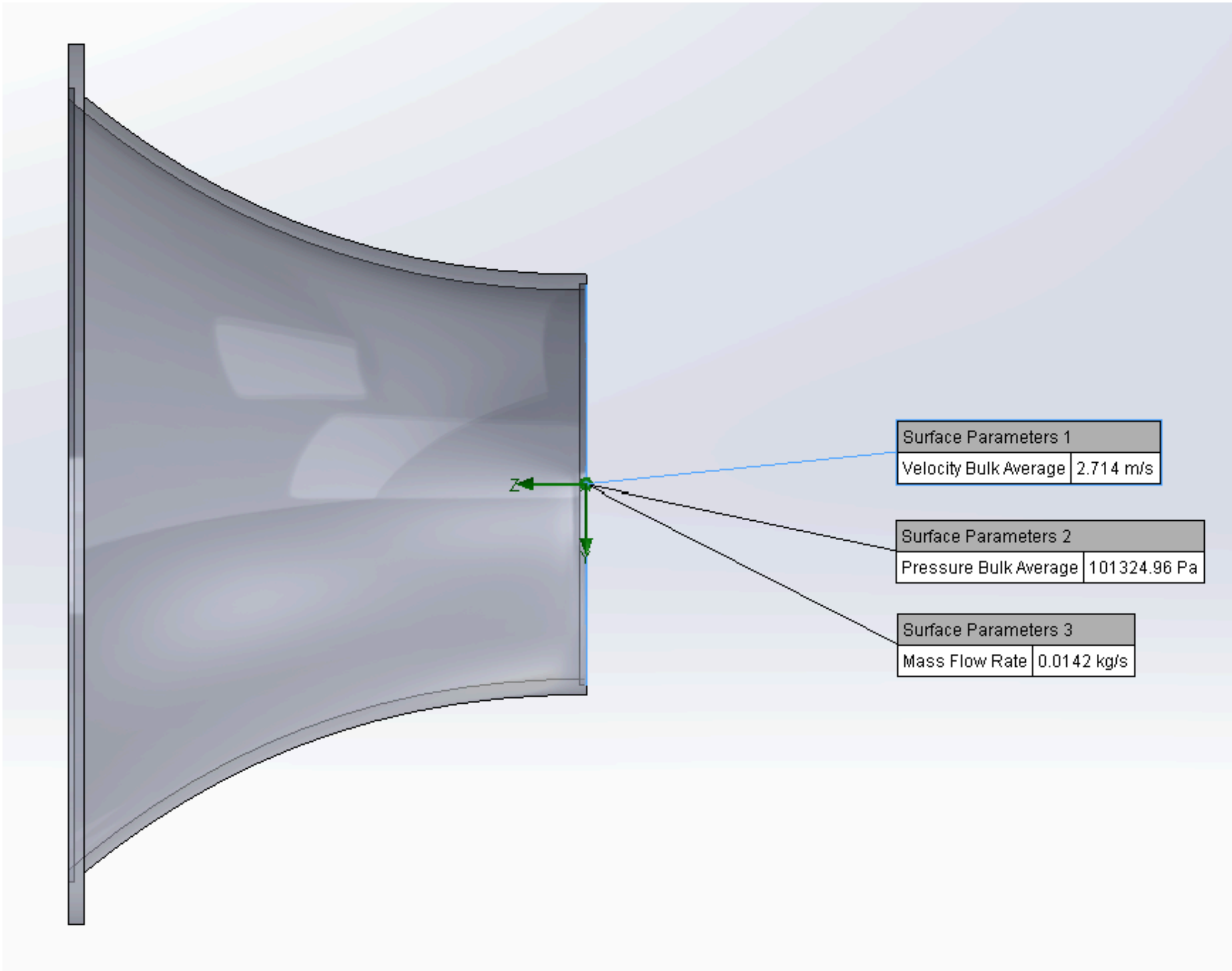
Pressure Profile



Pressure Profile

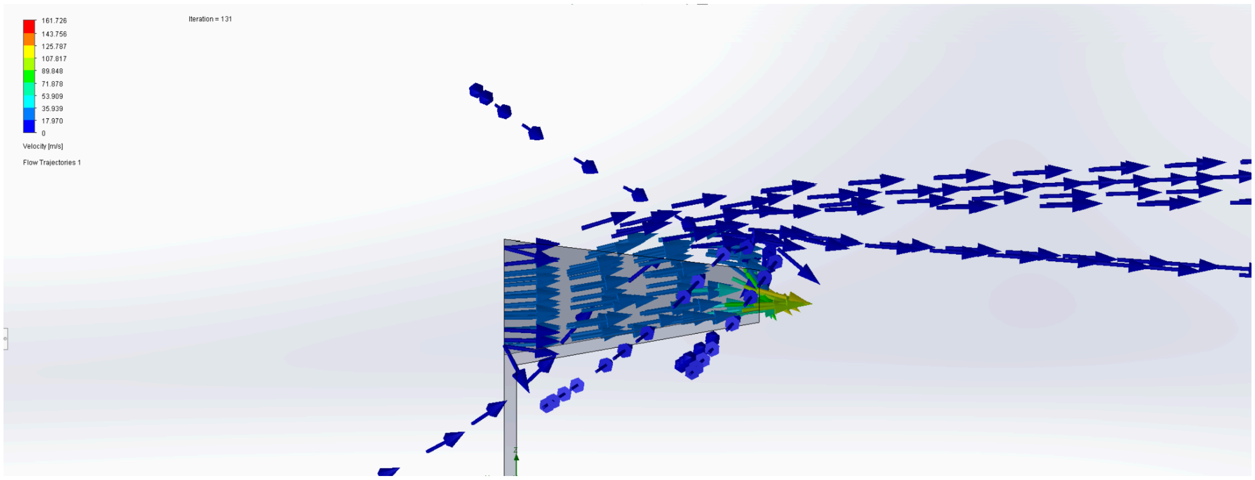


Velocity Profile

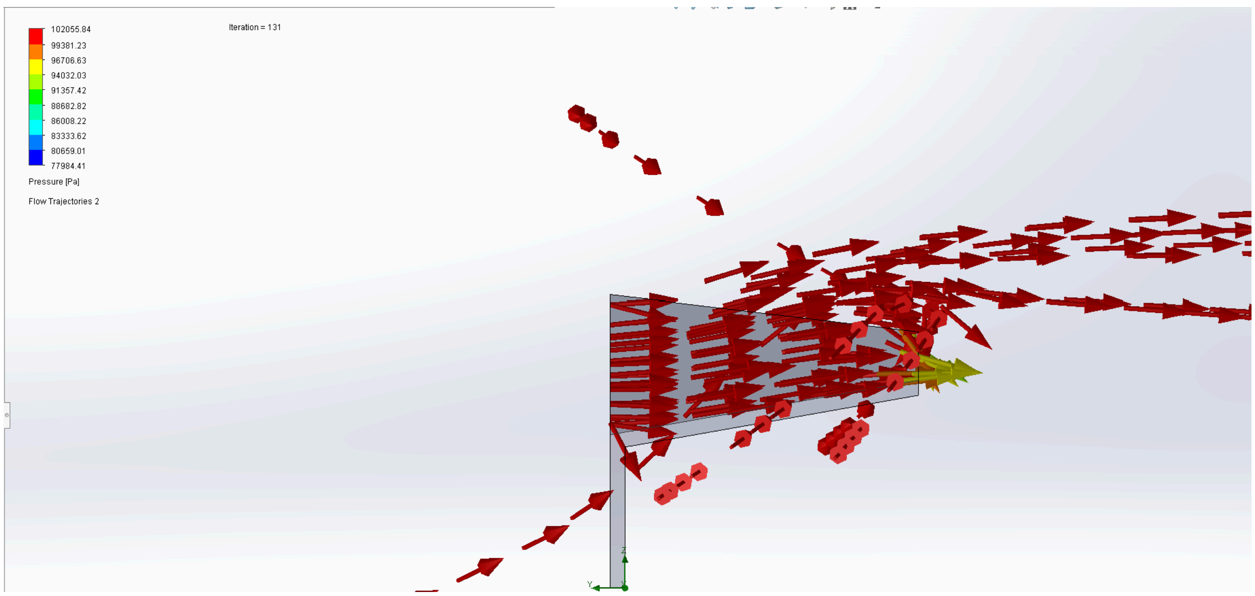


Iteration 2 Outlet Parameters

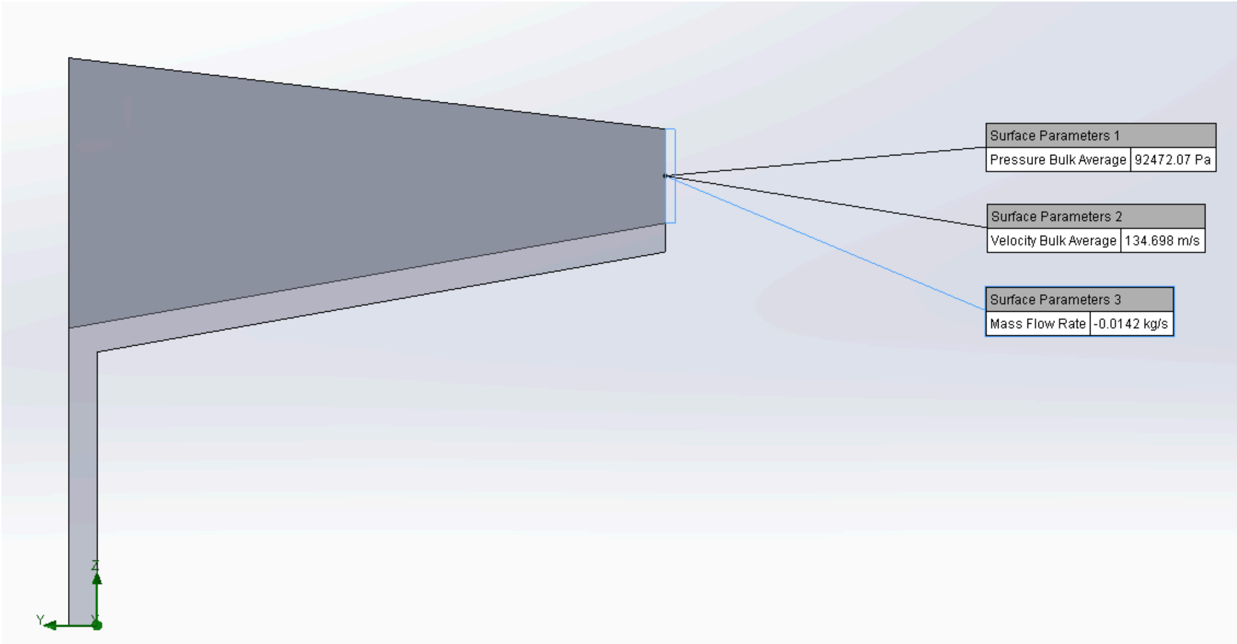
Ramp



Velocity Profile



Pressure Profile



Ramp Outlet Parameters