Laboratory Fume Hood
ME 486C- Summer 2020
Team 5

Final Report

Talal Alshammari

Zachary Bell

Bryce Davis

Shirley Hatcher

Project Sponsor: Dr. Zachary Lerner

Instructor: Dr. Sarah Oman

DISCLAIMER

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EXECUTIVE SUMMARY

A laboratory fume hood is commonly used to eliminate health hazards to those working with dangerous materials. Carbon fiber is a material with many beneficial properties such as its high strength and lightweight properties. Sanding operations are a necessary procedure to shape or manipulate the material into a more useful form. These sanding operations produce particulates and epoxy fumes that have been proven harmful and potentially fatal to individuals exposed to these byproducts. Laboratory Fume Hoods are devices that are specifically designed to eliminate the hazards of working with dangerous materials. The Fume hood designed for this application consists of the fume hood box connected to an exhauster with an attached filter. The fume hood box is the working space where the sanding operations will take place. The exhauster is attached to the top of the fume hood box, drawing the air flow into the exhauster which will be expelled out of the system. The filter is attached to the top of the fume hood box to extract the carbon fiber particles from the air flow before entering the exhauster.

The design process included many consultations with the client, Dr. Lerner, to determine the most efficient way to implement the lab fume hood into the Biomechatronic lab. The team decided to have a HEPA air filter on the exhauster intake to collect carbon fiber particles. This will allow the client to change out the air filter once it becomes too full and the air flow is no longer sufficient. The testing being done will involve pressure differential measurements as well as flow rate measurements. The pressure drop will increase, and the flow rate will steadily decrease as the filter collects the carbon fiber particles through normal use. The shape of the fume hood was determined by the team to maximize the flow rate without producing any stagnation point or dead zones in the airflow.

The final product is a pyramidal fume hood shape with a circular HEPA air filter. The exhauster is attached at the top of the device with the filtration system contained at the top of the attachment. There is a filter safety monitor installed to ensure a safe operational environment. This consists of a differential pressure transducer with two static pressure taps located at the intake and discharge of airflow through the filter. This system will be used to recommend when the filter should be replaced. The material of the structure will be polyethylene due to the lightweight and chemically resistant properties of the material. The device will be fabricated using resources through NAU. Fabricating the structure at NAU will keep the final product affordable and close to the budget.

Testing procedures will need to be performed once the device is implemented into the lab. The two primary testing parameters include the airflow and filter effectiveness. The airflow will be tested at NAU using an anemometer to test for possible stagnation points and dead zones in the airflow through the system. The filtration system will be tested using fine particulate capture pads to effectively capture any carbon fiber particulates not contained in the HEPA filter. The testing procedures are iterative, and the device can be repaired if the system does not pass a test. If any leaks or dead zones are identified, the structure can be repaired and the filtration system can be calibrated. The system should function properly and reliably for the fabrication of mobility impairment devices. The final product will aid the Biomechatronic Lab by providing a safe and efficient workspace. The final product is a durable and portable design that can be positioned and functional at various points throughout the lab.

ACKNOWLEDGEMENTS

Team 5 would like to acknowledge Dr. Zachary Lerner for creating the opportunity to design and create a laboratory fume hood. He was flexible with budget and was open to ideas brough to him by the team to enhance the design. As the project sponsor and client, the project would not have been possible without him.

We would like to acknowledge Dr. David Trevas for helping us get started on the project and always being accepting and understanding when we had questions. He assisted us through the second semester when he was not the faculty facilitator to ensure we would provide a functional final product. Dr. Trevas donated and let us get experience with the pressure transducer, Arduino board, breadboard and cables and assisted with Arduino coding and testing as well.

We would like to thank Dr. Baxter for meeting with us and allowing us access to the velocity probe and the fine particulate capture pads in order to test our final product. He was open to answering all questions and led us in the right direction of the testing procedures.

We would like to thank Dr. Oman for assisting us throughout the final semester of capstone. We appreciated all the feedback and assistance when the project took a different direction. We all really appreciated the extra time allotted and the amenability of the class due to the online nature.

TABLE OF CONTENTS

Contents

1 BACKGROUND

1.1 Introduction

Dr. Zachary Lerner is the project sponsor and client of team 5's fume hood project. His research is focused on developing mobility impairment devices for children afflicted with walking impairments due to cerebral palsy. Carbon fiber is an efficient material choice for mobility devices due to its durability and lightweight properties. NAU's Biomechatronic lab would benefit from developing carbon fiber parts in house rather than outsourcing for fabrication. However, carbon fiber is hazardous to work with due to the emission of epoxy fumes and fine particles. The objective of the overall project is to neutralize the threats associated with carbon fiber. The laboratory fume hood presented will ensure a safe working environment allowing for the efficient fabrication of the mobility impairment devices.

1.2 Project Description

The Project requirements and specifications were provided by Dr. Lerner. The Biomechatronic Lab is already in possession of the EBR 500 Exhauster provided through a previous capstone team. A primary requirement for the team was building a fume hood structure that will operate effectively with the existing component. The initial consultation with the client gave the team initial design parameters and requirements. The fume hood designed should be portable within a building and desktop sized, having dimensions of 4ft wide by 2ft deep by 3 ft long. The flow rate through the hood should be consistent and should not contain any dead zones of stagnant air. Stagnation points could potentially cause a collection of carbon fiber particulates which could present a hazard to those working in the fume hood. Additional requirements given to the team were specific to the lab the device will be used in. Safety was a main priority of the team as well, which led us to create and implement a filter operational safety monitor to indicate when the filter should be changed for optimal use

2 REQUIREMENTS

Several consultations with Dr. Lerner provided clear customer requirements which the team was able to relate to engineering requirements. The Biomechatronic Lab needed a portable fume hood to sand and fabricate carbon fiber in a safe manner. There are some safety precautions in place now, but a Lab Fume Hood would be more beneficial and provide greater safety measures. An exhauster was purchased and anything that was to be built must be compatible with existing equipment.

2.1 Customer Requirements (CRs)

1.Safe to Operate - The final product must meet all OSHA standards and be safe to routinely use in a lab setting.

2.Reliable Design - The design must be efficient and effective. The fume hood will be in regular use and must be in a functioning and reliable state.

3.Compatible - The fume hood design must be built around the existing exhauster already owned by the Biomechatronic Lab. The team cannot propose changing the exhauster.

4.Durable - Materials and filter types must be chosen to be durable, the carbon fiber being removed should not cause severe damage to the fume hood.

5.Portable - The fume hood and exhauster should be portable within a lab setting; the design should not be permanently fixed or unable to be moved.

6.Combined Weight - The combined weight of the final product should remain under 60 lbs.

7.Filter Assessment - Filter life readings should be available to lab workers to maintain a safe operational level.

8.Eliminate Epoxy Fumes - The fume hood and exhauster should effectively remove the threat of epoxy fumes which can be harmful to human life.

9.Remove Fine Carbon Fiber Particulates - The fume hood and exhauster should eliminate the threat of fine carbon fiber particulates which can be harmful to human life.

10.Within Budget - The budget is flexible but should remain around $400. Client updates and communication will be necessary in determining the final budget.

2.2 Engineering Requirements (ERs)

The client clearly specified the dimensionality of the fume hood. The volume, weight, usability and maneuverability of the device were numbers given to us by Dr. Lerner. The volumetric flow rate and air velocity were determined through research of the exhauster given to us. The durability is based on existing fume hood designs and the material strength of plastics used currently. The pressure drop, filter assessment, and particulate capture are all determined experimentally and through independent research of the team. Engineering requirements are tabulated in table 1 below.

Table 1: Engineering Requirements

Engineering Requirements	
Requirement	Units of Measure
Dimensionality	2 x4 x3 feet
Weight	<80 lbs
Volumetric Flow Rate	2400 CFM
Air Velocity	100 FPM
Pressure Drop	Double initial pressure reading
Maneuverability	Transportable within building
Durability	200 Kpsi
Filter Assessment	Seconds
Usability	Compatible with EBR 50 Exhauster
Particulate Capture	0-80% Max capacity (lb/ft^3)

2.3 Functional Decomposition

The primary purpose of this capstone team is to provide a safe and efficient workspace to create mobility impairment devices within NAU's Biomechatronic lab. The goal of the team is to eliminate the threat associated with carbon fiber fabrication while using existing components provided by the lab. The primary function of the fume hood system includes containing the toxic fumes and harmful particulates within the filtration system, exhausting the clean air back into the environment while eliminating harmful contamination, and maintaining and monitoring the safety operational standard of the system. Figure 1 displays the functional decomposition for the laboratory fume hood system.

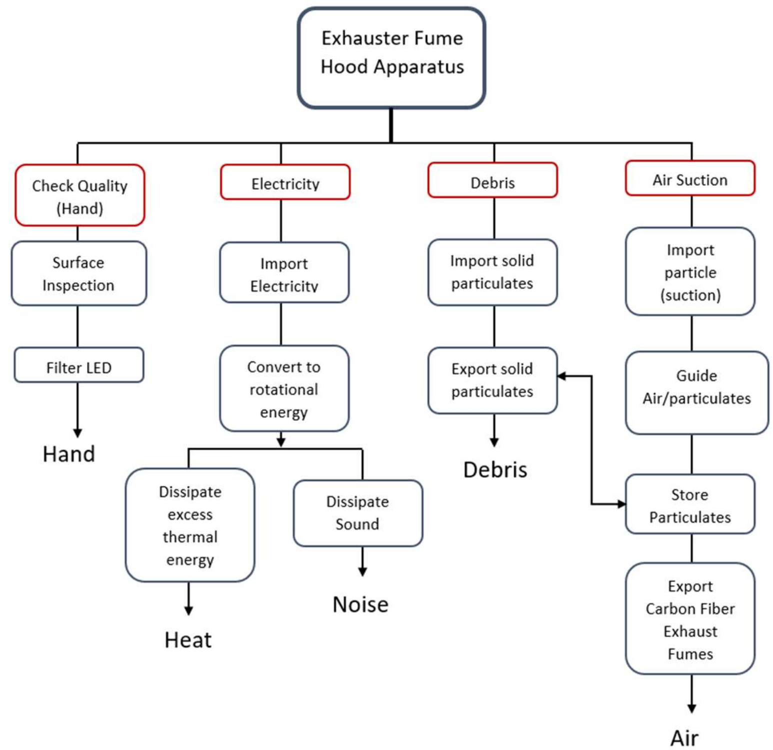


Figure 1: Functional Decomposition

2.3.1 Black Box Model

Our black box model shows the input and output functions of the laboratory fume hood system. This model relates the functional decomposition inputs and outputs to one another on a simplified basis. It relates the input of materials, energies, and signals to their respective outputs as the system operates. The signals include a simple on off switch on the exhauster. Energy includes electrical energy provided by the wall outlet. The materials involved include hands, exhaust fumes, and harmful particulates. This model is displayed in figure 2. The Black Box Model helped the team to break down each input and output the final product will be responsible for. This information allowed the team to further breakdown the system functional decomposition to included subsystems within the apparatus.

Figure 2: Black Box Model

2.3.2 Functional Model/Work-Process Diagram/Hierarchical Task Analysis

The team analyzed the functional decomposition by breaking down each component into a full system and subsystem decomposition to further break demonstrate each individual task. The subsystem functional analysis model illustrates three points in the exhaustion system. The three points consist of neutralizing threats of harmful fumes and carbon fiber particulates, capturing harmful particulates, and maintaining a safe operational level of safety for the system. The three subsystems are vital to the operation and performance of the exhaustion system. Figure 3 displays the subsystem functional decomposition.

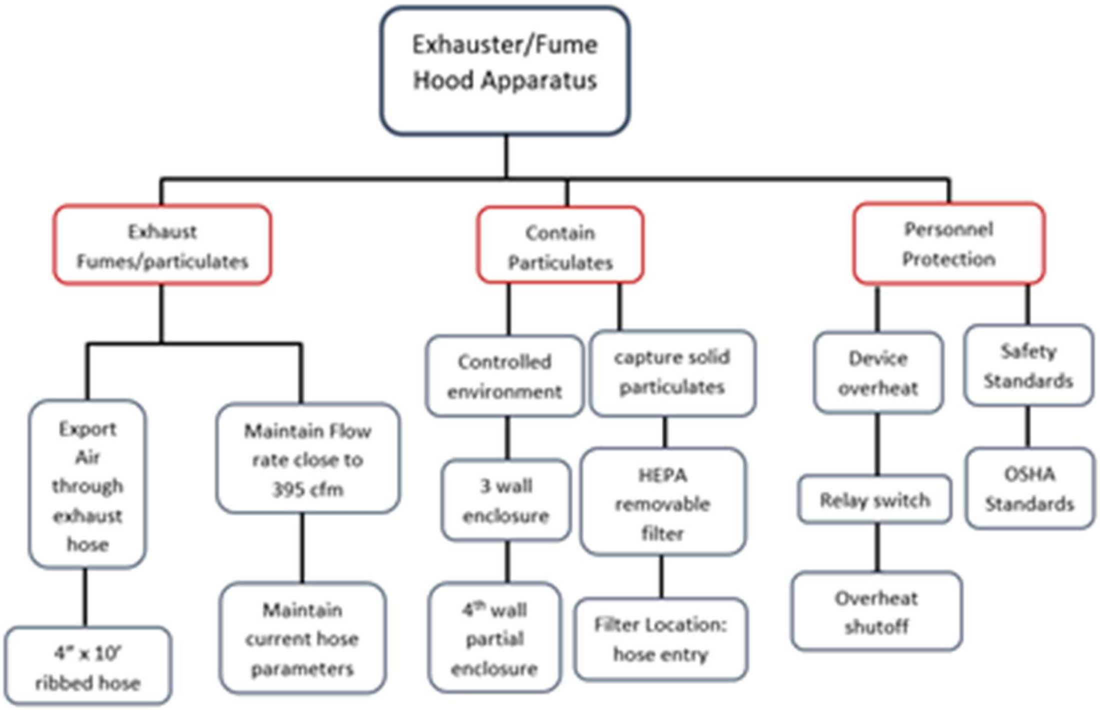


Figure 3: Subsystem Functional Decomposition

2.4 House of Quality (HoQ)

FUME HOOD (HoQ)	Weight	Volumetric Flow Rate (lb/ft^3)	Device manuverability/portability	Dimensional area (ft^2)	Weight (Lbs.)	Ventilation velocity (ft/min)	Particulate Fume Capture (lb/ft^3)	Useability	Filter change assessment time (seconds)	Pressure Drops across device (SPWG)	Durability/Fracture toughness (ft-lb/in^2)
Customer Needs											
1. Table Top Fume Hood	5	1	3	5	5	3	5		3	3	3
2. Compatible with Exhauster	5	3				5	5	5	3	3	
3. Hepa Filter	4					1	5	5	3	3	1
4. Particulate Export	4	5	1	1	1	5	3	3		3	3
5. OSHA	5						5		3		
6. Reliability	4						5				
7. Minimize Inlet Pressure Drop	2	1				3	5			5	
8. Filter Light Indicator	1								5		
9. Extended Hose	2	1	1		1	1		1		3	
10. Durability	3										5
Absolute Technical Importance (ATI)		44	21	29	31	72	137	59	62	70	46
Relative Technical Importance (RTI)		7	10	9	8	2	1	5	4	3	6
Target ER values		0.75	N/A	25	100	4524	0.75	N/A	N/A	5.3"	N/A

Figure 4. Fume Hood House of Quality

2.5 Standards, Codes, and Regulations

The engineering standards that have been made by national and international committees is a very useful tool when designing and building any device. This is because the standards that they provide gives the team a starting place when designing the project and a guideline to adhere to while in the design and implementation process and beyond. The two most important standards for this project are the standards provided by OHSA in relation to chemicals and ISO for the selection of a proper filter. These are important as the device is designed to increase safety of the user while working with hazardous materials. OSHA standard 1910.1450 thoroughly details the laboratory safety measures that need to be in place while someone is working with any chemical or material [1]. This is to minimize exposure to dangerous materials without proper equipment as well as prevent a worker from getting injured while interacting with any sort of hazardous material. The standards that the team has been using is in a tabulated form below, table 2.

Table 2: Standards of Practice as Applied to this Project

Standard Number or Code	**Title of Standard**	**How it applies to Project**
OSHA 1910.1450	Occupational exposure to hazardous chemicals in laboratories	Helps in the design of the user-device interface.
ISO 16890	Air filters for general ventilation	Helps with selecting the correct filter for use in the device.
ASTM D543	Standard Practice for Evaluating the Resistance of Plastics to Chemical Reagents	Helps with testing the device to ensure that the device will not have any adverse reactions to the particulates and epoxy fumes.
IEEE 829-2008	IEEE Standard for Software and System Test Documentation	Helps with testing the electronic additions to the device to ensure that they will work consistently.

3 DESIGN SPACE RESEARCH

This chapter of the report focuses on the research and initial analysis of current market model fume hood systems. From this research and analysis benchmarking was completed and goals and requirements were established as a basis for improved learning and comprehension.

3.1 Literature Review

Literature reviews were conducted thoroughly in ME 476C with the intent to research and validate all necessary components for a successful manufacture and design of a fume hood. Documented research and analysis included the relationships between the EBR 50 exhauster fan to its performance curves. This information was conducted with the provided performance curve diagrams within the EBR 50 fan manual. Performance curve research related the relationship between the flow rate and pressure loss within the system. Research concluded that when the flow rate increased the pressure drop also increased in a nonlinear relationship. Using this relationship and information the team was able to determine the required flow rate given the nozzle area and pressure drops. The EBR 50 fan runs optimally at 395 cfms with an initial pressure drop of 5.3 inches.

We also conducted research and analysis for air quality and particulate filtration. The information that was gathered included testing standards, filtration class types, and testing methods. The filter class system is based off of particulate size and categorization of filters that are found in EN 779 and EN 1822 [1]. For the project the filter is constrained to a HEPA style filter which has an efficiency of 99.97% at removing particulates that are .3μm or larger. In addition to this, the HEPA style air filter is limited to air flow between the ranges of .1 to 1 m^3/sec for a single filter [2]. EN 779 has test standards for various types of filters including coarse filters, medium filters and fine filters. These filters are differentiated based on filter test standards before EN 779:2012 [3]. A standard for counting airborne fibers and asbestos particles is beneficial for the team as this test can be replicated in the fume hood design to ensure the functionality of the device [4].

An important component of the overall design was the research and validation of material selection. The material chosen would need to be strong, lightweight, durable, and resistant to any outside element including corrosion and material failures. Research was conducted through scientific articles, web searches, and common current market models. This research resulted in the material selection for polyethylene plastic as the structure material for our fume hood design. Polyethylene is a widely used material for its strength, durability, and cost. Polyethylene is also a common structure material in molded fume hoods.

Research and analysis concluded with the containment and efficient exhaustion of the fume hood system. Information was gathered from a variety of sources which included web searches, scientific and journal article research, and thorough analyzation of current market research. Information gathered included the most prominent designs on the market today. The top two designs are ducted ventilation hoods and ductless ventilation hoods. This information was gathered from Labmanager, a website that focuses on lab safety equipment [5]. The third design idea came from a lab study from Singapore that studied diverse types of ventilation hoods in high performance low flow circumstances. Engineers in that report were studying the effects of flow rate on several types of fume hoods with the intent of decreasing the fume velocity vortex within the fume hood. This decrease in the vortex allows for a greater exportation of the harmful toxins and particulates [6]. The third source studied that provided relevant information included the proper placement of fume hood ventilation systems within a lab. Proper or recommended locations include locations away from doors, windows, any type of air diffuser, or in locations where personnel do much of their work [7]. The fourth source studied related the particulate size and density to the overall efficiency of particulate capture. The report showed that as particulate size increased the efficiency of capture decreased rapidly [8].

Figure 5 shows this relationship with two different density materials.

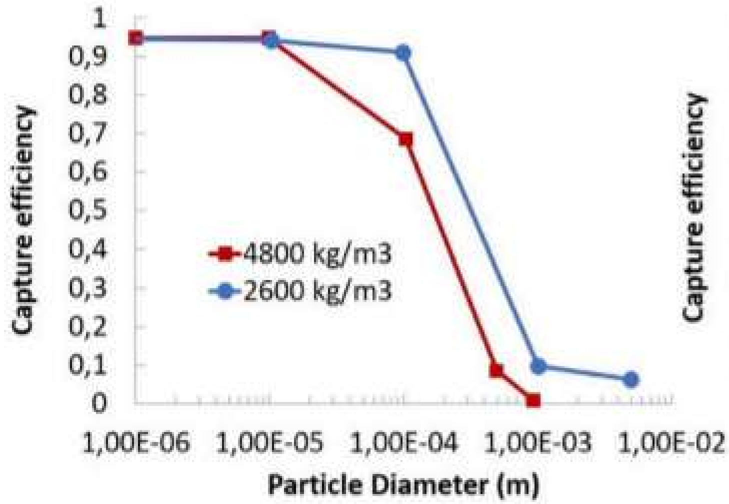


Figure 5: Capture Efficiency for two types of materials [8].

From this experiment the research team determined that particle density had negligible effect on the capture efficiency. The main component of their research explained that particle diameter played the biggest role. Particles with larger diameters fell back to the device floor once suction ceased [8]. Lastly, the fifth source studied on fume hood design focused on fume hood structure and how to avoid re-circulation zones and vortex points within the system. Eliminating these zones, or even reducing them, allows the exhauster to function at a more efficient level and even at a quieter rate [9]. Studies showed that fume hoods with more rounded edges and curves proved more efficient than those with sharp bends. This report also studied the most effective placement of the fume exhauster hose to avoid additional eddied and vortex points [9].

3.2 Benchmarking

This section of the report contains detailed information on the specific aspects of the fume hood design process from a benchmarking standpoint. Our previous literature searches led us to some beneficial information that will be imported into the design process for the most efficient fume hood. We explored benchmarking data with respect to the overall system level and the subsystems that accompany the overall design. Due to the nature and regulations surrounding Covid-19 the team was unable to conduct in person research and analysis on current market fume hood models. However, benchmarking was done with extensive client input as well as professor and faculty input from multiple sources at Northern Arizona University. Sources included NAU cline library resources alongside library engineering specialist Bridget Wipf, Dr. David Trevas who serves as the Arduino club advisor, and Dr. Baxter who provided the team with helpful information regarding testing the airflow within the system and calibrating the pressure sensor. Due to restrictions we were not able to perform any hands-on testing but were able to adapt to the situation with theoretical testing.

3.2.1 System Level Benchmarking

There are several designs that have been developed for the fume hood and each design works on a different primary principle. Comparing the requirements with the three different designs we were able to find relationships that correlate with our design ideas that relate to project requirements. These existing designs are operating on three different principles of capturing and extracting fumes and particulates. It consists of an air inlet system with the pressurized nozzle that generates the difference of pressure and will cause the force flow to go out from the exhaust door. In addition, designing on the similar principle which takes air inlet and passes the air out from the exhaust with the toxic fumes is needed in this project. Three existing designs have been presented in the following sub sections of this chapter.

3.2.1.1 Existing Design #1: In-line Fume Hood

In this fume hood design, all the components work in a single line to perform the extraction. This design comes with a bypass in the airfoils, with a slash that pushes from the top to bottom sides. It then generates the necessary force in the compartment of the slash with the lower side, which then operates at different levels of pressure [10]. This design is pictured in figure 6 below.

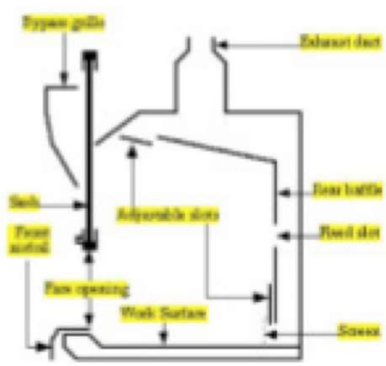


Figure 6: Inline Fume Hood Current Market Design

3.2.1.2 Existing Design #2: Plume Scaling Fume Hood

Another current market fume hood design is the plume scaling fume hood. This technique of fume hood removes the fumes and particulates with the plume photographic method. This method uses a camera lens which detects the fumes through visible surveillance. This camera lens ensures that all fumes and emissions are evacuated from the fume hood system. This system extracts fumes and particles in a similar format to a ductless fume hood by extracting all particles and fumes through a hose and fan but ensures efficiency with the attached camera lens feature. This model is pictured in figure 7.

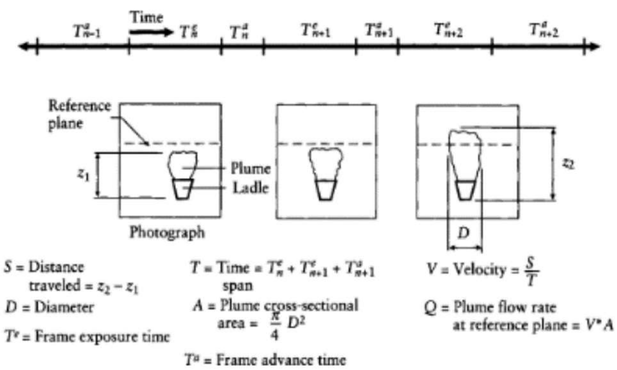


Figure 7: Plume Scaling Fume hood design with photographic lens

3.2.1.3 Existing Design #3: Low Flow Fume Design

This system design used the mixture of bypasses, slashes, and baffle airflows to extract fumes and particles from the system. The primary purpose of this design is to increase aerodynamics of the fume hood and its extraction process. This low flow design also aims to decrease operation cost that is associated with lower face velocities [6]. With increased aerodynamics and bypass design this model was able to reduce vortex flow inside the fume hood which decreases the risk of vortex eddies and re-circulation zones within the system.

Figure 8: Low flow fume hood design with bypass

3.2.2 Subsystem Level Benchmarking

Within the benchmarking data we explored material selection, specifications of air filters, and ways to enclose the fume hood apparatus based on design and efficiency. The top three current market designs and solutions were examined and analyzed for our team understanding and concept analysis.

3.2.2.1 Subsystem #1: Material Selection

Lab Fume Hoods must be made of durable and effective materials to ensure safe operational standards. While each fume hood can be designed specifically for the hazard being presented, there are some commonalities in methods for choosing a material. Safety is the most important aspect when choosing a material and cost usually determines how safe you can go while staying within budget. The material being utilized in this project is carbon fiber. The following materials are in common practice today and would be effective for our application.

3.2.2.1.1 Existing Design #1: Polyethylene

Polyethylene is a widely used polymer for many reasons. This material is durable, economical, and highly chemically resistant. There are different densities available that can be chosen based on project specification. This is a viable option for the current project as this material would be easily damaged by carbon fiber. For a general density of approximately 955 kg/m^3, the yield strength provided would be roughly 2.7x10^7 Pascals [11]. This would provide a viable option for the fume hood material selection.

3.2.2.1.2 Existing Design #2: Polypropylene

Polypropylene is another common plastic used for fume hoods. This material is available in homopolymer or copolymer composites but the application for the two is essentially the same. Both have a high strength to weight ratio, chemical resistance, and high impact resistance. However, this material is highly flammable. An average density of this material is .9 g/cm^3 with a yield strength of 35 MPa [12]. This material may be applicable to our fume hood.

3.2.2.1.3 Existing Design #3: Polycarbonate

Polycarbonate is a high-performance polymer that is lightweight, chemical and heat resistant, and has a high impact strength. The average density is 1.1 g/cm^3 and the yield strength is 65 MPa [13]. Polycarbonate maintains an advantage due to its high fire-resistant quality. However, Polycarbonate is vulnerable to hydrocarbon. Testing may need to occur before this material is proceeded with.

3.2.2.2 Subsystem #2: Air Filtration Calculations

Air Filters come in many classifications and each classification has its benefits and downsides for the fume hood project. For the fume hood project the filter class chosen has to be as efficient as possible, be able to remove harmful particulates from the air before being exhausted into the atmosphere, and not create a large pressure drop when a clean filter is present in the device.

3.2.2.2.1 Existing Design #1: Coarse Filters

Coarse filters are a subset of filter classifications that are labeled as having average arrestance in accordance with ashrae dust at final pressure drop of 250 Pa [4]. This type of filter is then further separated down into categories based on the average percentage of arrestance the filter has. These filters can capture larger particulates however as the fume needs to be designed with carbon fiber particulates and epoxy fumes in mind a filter that is able to capture smaller particulates.

3.2.2.2.2 Existing Design #2: Fine Filters

Fine Filters are a subset of filter classifications that are categorized as having minimum and average efficiency measurement with an optical particle counter[4]. This type of filter is further categorized in accordance to its average efficiency percent. These filters are able to handle smaller particle sizes but this filter is unable to filter out the epoxy fumes which are dangerous to humans.

3.2.2.2.3 Existing Design #3: High Efficiency Filters

High efficiency filters describe HEPA and ULPA filter types. HEPA filters are able to remove 99.97% of all particulates from air and ULPA filters are able to remove 99.9995% of all particulates from air [4]. These filters are also able to capture extremely small particles with HEPA filters being able to capture particulates sized .3μm or larger and ULPA filters are able to catch particulates sized .12μm or higher [4]. These filter types are what would be best for the fume hood as they are able to catch 99.9% of the particulates from carbon fiber.

3.2.2.3 Subsystem #3: Containment of carbon fiber particulates and noxious fumes

This subsystem is the overall basis for the project. If we were unable to contain these harmful particulates or exhaustion fumes the entire system would be classified as a failure. The purpose of collection and containment provides a safe and efficient workspace for working with carbon fiber elements in the Biomechatronics lab here at Northern Arizona University. There are various types of fume hoods on the market today, each with their own specific function. We looked at these various models and compared them to our ideas and strategies. Most fume hood systems on the market focus on a design that creates a capture zone within the system which contains the harmful substances that are being worked with in that instance [5].

3.2.2.3.1 Existing Design #1: Ducted Fume Hoods

Traditional ducted fume hoods focus on removing the air within the structure entirely from the room or workspace. These specific type of fume hoods utilize a mounted exhaust fan or blower that pulls the harmful air and particulates up and through the fume hood and then out an exhaust port that leads outside the room or lab space [5]. Any and all harmful particulates/fumes are exported out and away from the workspace without re-circulating back into the workspace. We expect to use this type of exhaust fan in our design. We have been given an exhauster to work with, the Cincinnati Fan model EBR 50.

3.2.2.3.2 Existing Design #2: Ductless Fume Hood

Ductless fume hoods have comparable properties to the ducted versions with one major difference. These types of exhaustion systems rely on filters to capture and contain the harmful particulates and fumes and then re-circulates that air back into the system to recapture more particulates and fumes [5]. Instead of exporting the air, fumes, and particulates entirely from the room this type of system recycles the air for repeat usage in the system. We will also incorporate this type of fume hood into our system by applying a filter to the front of the exhaustion hose, before the particulates circulate through the motor. Our system will combine both types of fume hood. Ductless by applying a filter to the front of the hose to capture all particulates and harmful fumes but ducted by exporting all remaining air and smaller particulates to the outside air.

3.2.2.3.3 Existing Design #3: Bypass Concept

One other prominent form of exhaustion systems is the Bypass concept. This concept introduces air from a bypass, typically at the top of the fume hood where the operators face is, and then blows that clean air across the length of the fume hood. This design ultimately works but isn’t the most comfortable or logistical used for the fume hood [6].

4 CONCEPT GENERATION

4.1 Full System Design #1: Water Based Filter

This design has a tray of water on the bottom of the fume hood the items being worked on will be at. This design is fully enclosed with the exception of the front access port and an outlet on the top for a fan to exhaust any of the fumes. This design can be seen in figure 9.There will also be a pressure sensor that will use LEDs to indicate when the air filter needs to be replaced. This design has the advantage of using multiple filtration systems to ensure the safety of the user. The primary disadvantage of this design is that the water filtration system will need to be changed out frequently. This creates an issue where any spilled water can create a safety hazard for the user and any people nearby. In addition to this the water tray will need another filter when it is being cleaned to ensure that carbon fiber particulates do not damage any existing infrastructure.

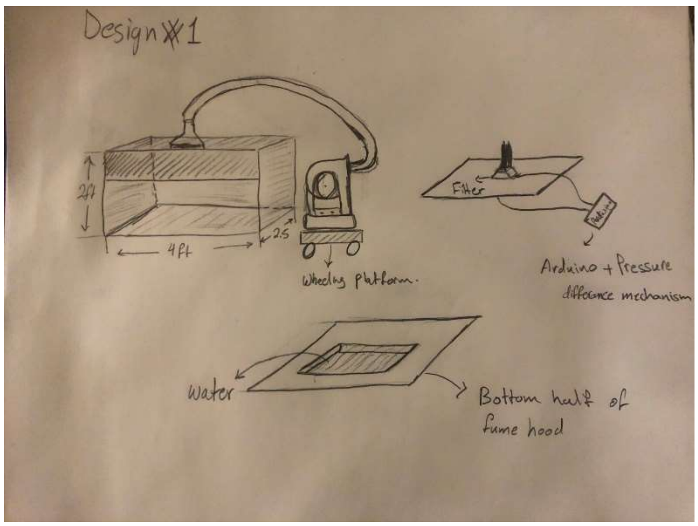


Figure 9. Water Based Filter

4.2 Full System Design #2: HEPA Style Filter

The second design concept utilizes the basic structure of a fume hood and uses a singular filtration system to simplify the device. This filtration system utilizes a HEPA style filter and an exhaust fan to remove any particulates and fumes within the device. The design can be seen below in figure 9. This type of filter is chosen for this design as it is able to remove 99.97% of all particles and fumes in the air. In addition to this the system will utilize a pressure differential system in order to determine when the air filter needs to be replaced. The primary disadvantage to this design is its potential cost. Because of how much material the HEPA filter is able to remove from the air, the filters tend to be more expensive than other types of filters.

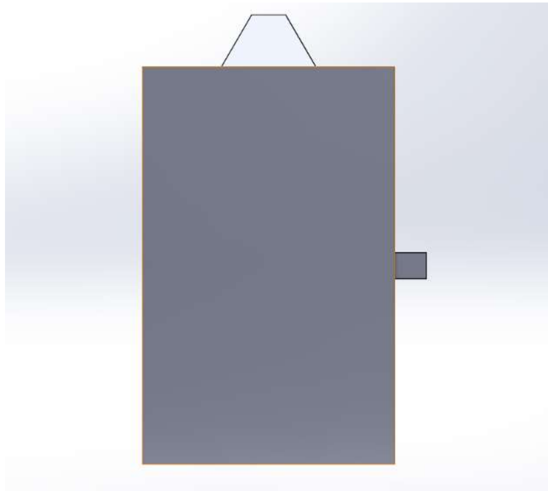


Figure 10. HEPA Style Filter

4.3 Full System Design #3: Carbon Based Filter

The third design concept is very similar to the second one in that it also utilizes a single exhaust port and air filtration system. However this design is different by using a carbon based filter and by having an adjustable front panel. The design can be seen below in figure 10. with the front panel fully lifted. The carbon based filter has the same efficiency as a HEPA filter but slightly cheaper than one. By having an adjustable front panel the user will be able to more easily move carbon fiber parts in and out of the device.

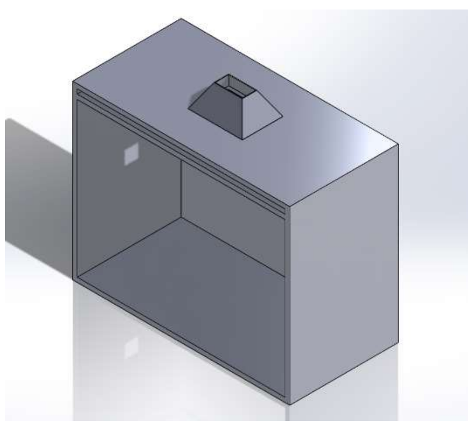


Figure 11. Carbon based filter

4.4 Full System Design #4: Fans Filtering System

For the fourth design concept the device will have the same box-like structure, but the back wall will be made of 4 fans with a connection to the primary exhaust fan. This design will be using either 4 filters, one placed in front of each fan, or a single large filter that will cover all of the fans. The design can be seen in figure 11. The design would be able to filter more air and maintain a safe work environment however it will require more energy to power the fans and will have increased costs due to the addition of the fans and the use of more filters. Additionally it will require multiple pressure sensing devices which will further increase the cost and likely go over budget for the project.

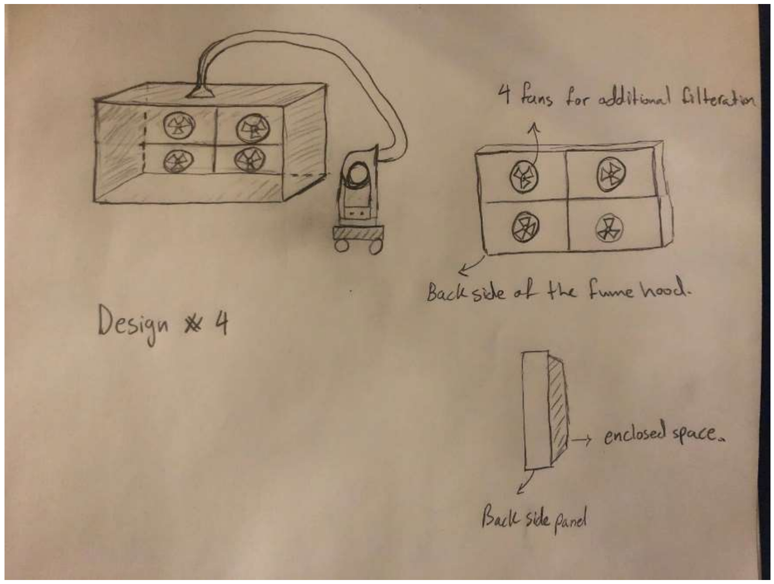


Figure 12. Fan Filtering system

5 DESIGN SELECTED – First Semester

This chapter of the report contains detailed information regarding the first semester design and implementation of our proposed fume hood. This includes the detailed 3-D CAD modelling renderings from the first semester of our capstone assignment.

5.1 Design Description – First Semester

The original design used from ME 476C was a basic rounded pyramidal shape with a cuboidal bottom. This included a completely open front, with no sash or enclosure for the 4th wall. The design incorporates design positives from multiple current market models. These positives included rounded edges that reduce the overall drag within the system by a range of 30-50% as compared to sharp edged models. These rounded edges help reduce the risk of vortex eddies, dead zones, and re-circulation points within the system. Design positives also include a pyramidal ceiling which draws the particles and fumes to one central location without losing suction power and overall efficiency. This design was chosen as a starting platform for the team to work from due to its simplistic shape and ease of alteration. From the end of ME 476C until the conclusion of the capstone assignment, this design has varied and been altered according to team, advisor, and client recommendation. This implementation was meant to be molded as one part. The exploded view assembly sheet can be seen in the appendix.

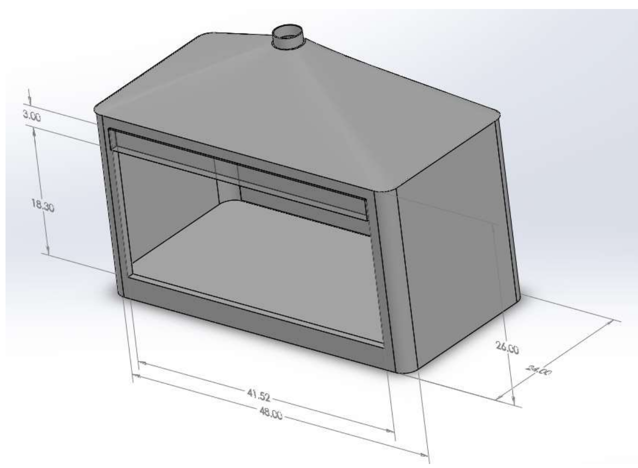


Figure 13: Final Proposed Fume Hood Design from ME 476C

Air flow calculations were done to make sure that this device selection would have sufficient airflow moving through the system to remove the carbon fiber particulates and epoxy fumes. Starting from the volumetric flow rate of the exhaust system the team was able to find that the device was able to meet all air flow requirements for removing the particulates and fumes from the working area.

Other design solutions that were implemented within the first semester included the material selection of the fume hood shell, filter selection, and an Arduino pressure system to monitor filter capacity and replacement. From the first semester of capstone we determined through research that the best material for use within this system would be polyethylene plastic. This decision was made with the assumption that polyethylene is durable, lightweight, and cost-effective. We needed a shell material that reduced or eliminated the harmful effects that accompany carbon fiber. Naturally, carbon fiber is corrosive to most metals since it is naturally electromagnetically charged. This specific type of corrosion is called galvanic corrosion. This type of corrosion quickly corrodes most aluminums and other types of metal. However, plastics are resistant to this type of corrosion which helped decide our final material selection for this shell.

The team collaborated with multiple faculty members and engineering professors throughout the first semester who provided helpful insight into Arduino and pressure sensing systems for use within the project. As a design idea, the team desired to implement a pressure sensing system that would alert the user that the filter was full of particulates and needed to be changed. The basic groundwork and knowledge were laid during this semester. The Arduino information and equations were set and were ready for future testing in ME 486C. Pressure sensor technology can be shown in figure 14 below.

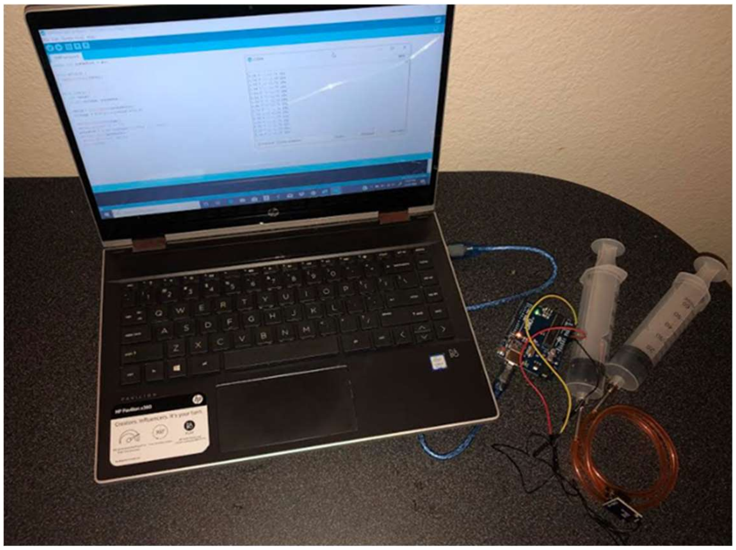


Figure 14: Differential Pressure Transducer with Arduino Uno

Filter selection was also made in this semester. The team conducted research on filters and specifications according to OSHA and client standards. Research determined that a HEPA filter was necessary for success within this project. HEPA filters adequately capture and extract up to 99.97% of all particles, dirt, dust, odors, etc. of up to 0.3 microns in size. They are known for their efficiency and durability while providing a safe and healthy atmosphere in which to operate. With this information and assumption, the team chose the Levoit LV-H132 filter with a three-stage filtration process. Stage one of the filter uses a fine preliminary filter that neutralize airborne bacteria and mold. The second stage of the filter houses the true HEPA filter that is responsible for the capture and retention of the larger particles within the system. The final stage of the filter captures and eliminates the harmful and toxic fumes and odors that are extracted from the fume hood shell.

Figure 15: Levoit LV-H132 HEPA filter

5.2 Implementation Plan – First Semester

Due to Covid-19 pandemic and the subsequent quarantine, the team was unable to produce a solid prototype in the first semester of capstone. The implementation plan for the following term needed to include time for manufacturing a prototype and subsequent tests on the initial prototype along with building and manufacturing the final tested product. At the start of ME 486C the team had planned to set aside two weeks for the manufacture and testing of the prototype with expenses kept to a minimum. The first prototype was meant to seek out and solve potential failures and other problems with the system such as leaks and poor design decisions. Moving forward from prototyping, the team will maintain constant contact with Dr. Lerner, regarding information pertinent to the success of the design. We expect to maintain and receive direction from him regarding materials and methods used for implementing the final design into his laboratory. Moving forward from this point the team will focus on manufacturing the product as quickly and efficiently as possible. After the final product has been manufactured, the team will conduct more in-depth test and analyses to ensure the overall safety and quality of the system. The Gantt chart shown below helps to further illustrate the research, analysis, testing procedures, and assignments for the final segment of this capstone assignment.

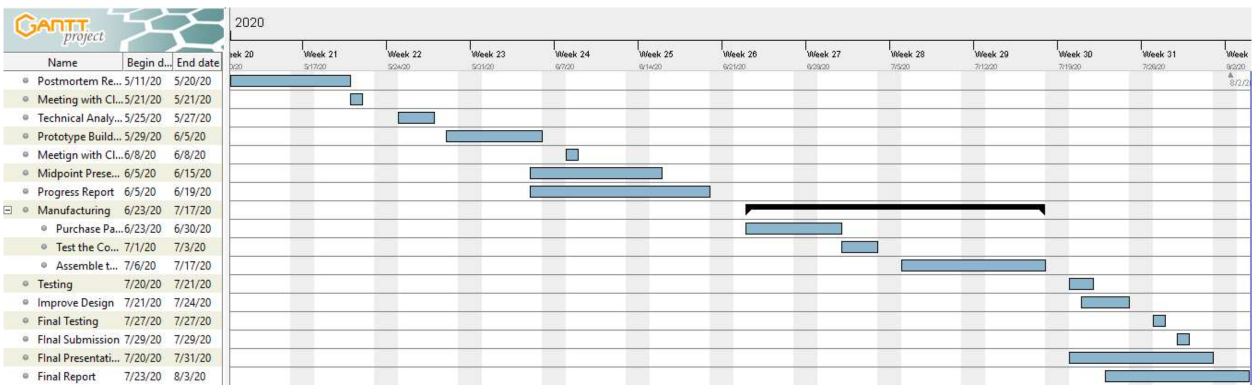


Table 3: Preliminary Gantt Chart for ME 486C

At the conclusion of the first semester of capstone we were able to derive a simple bill of materials that we could base our known expenses on. At the end of the first semester we did not have adequate information on whether or not the manufacture would be done at NAU or outsourced to a third party manufacturer, therefore those expenses will be shown in the bill of materials at the conclusion of ME 486C. The final projected bill of materials, excluding manufacturing costs is shown below.

Table 4: ME476C Final Projected Bill of Materials

Component	Cost per unit ($/unit)	Amount per unit	Total Material Cost	Purchase location
Levoit lv-h132 filter	$30	1	$30	Amazon
Arduino Uno Rev 3	$22.00	1	$22	Store.Arduino.cc
.187x24x96" PVC sheet	$72.48	1	$72.48	eplastics
0187x48x48 PVC Sheet	$72.48	1	$72.48	Eplastics
Buffalo tools dolly 1000lb rated	$18.32	1	$18.32	Home Depot
Pressure transducer	donated		$0	Dr.Trevas
LED Arduino light	$0.26	3	$0.78	Store.Arduino.cc
Photo resistor	$0.95	6	$5.70	Store.Arduino.cc
10 Kohm resistor	$0.036	10	$0.36	Store.Arduino.cc
221-ohm resistor	$0.27	1	$0.27	Store.Arduino.cc
4" worm drive clamps	$1.71	2	$3.42	Home Depot
Total Costs			$226	

6 IMPLEMENTATION – Second Semester

The major implementation that the team faced this semester was the manufacturing process. The client mentioned purchasing a prefabricated main structure (e.g. a large plastic container) that can be modified to meet the client requirement. From that, the team provided three options that the client was able to choose from. The purpose of those three options is to provide a better understanding of what the team is capable of after the unfortunate circumstances of COVID-19. Client feedback was taken into consideration in the manufacturing and assembly process, the team began to look for a large bin that could be modified as the main fume hood structure. The main box would be used as the fume hood structure and the 18-inch opening would be cut out to provide access to the workspace. The lid would be purchased and glued to the box as the bottom of the structure to prevent pressure drops. Polycarbonate sheeting can additionally be purchased and mounted to the inside of the structure to create the pyramidal shape inside the fume hood. A hole can be cut on the top of the fume hood to provide the attachment of the filter hose which will also contain the filter. The pressure differential device will be permanently mounted on the fume hood to display the filter capacity.

6.1 Design Changes in Second Semester

Manufacturing Option 1: Modified Polyethylene Bin

MODEL NO.	OVERALL DIM. L x W x H	INSIDE DIM. L x W x H	CU. FT. CAP.	BUSHEL CAP.	CAP. (LBS.)	WT. (LBS.)	PRICE EACH 1	3+	COLOR	IN STOCK SHIPS TODAY
H-1956GR	52 x 37 x 36"	42 x 26 x 30"	25	20	800	72	$360	$350	Gray	1 ADD

Figure 16. Main Component

Lid for Poly Box Truck - 20 Bushel, Gray

Hinged polyethylene lid opens easily at both ends.

- Fits 20 bushel Poly Box Trucks.

Enlarge & Video

SPECIFY COLOR:

MODEL NO.	DESCRIPTION	WT. (LBS.)	PRICE EACH		COLOR	IN STOCK SHIPS TODAY
			1	3+		
H-3529GR	20 Bushel Lid	26	$165	$160	Gray	1 ADD

SHIPS ASSEMBLED VIA UPS

Figure 17. Main Component Lid

Suntuf

26 in. x 8 ft. Polycarbonate Roofing Panel in Clear

Figure 18. Polycarbonate Sheeting

Component	Pricing
Polyethylene Bin	$360
Polyethylene Lid	$165
Polycarbonate Sheeting	$19.98

Total Manufacturing Cost = $549.98

Manufacturing option 2: Option Chosen by Client

The second potential option for our fume hood consists of manufacturing the fume hood using NAU resources and then assembling it. This option eliminates most of the cost of the device; however, it requires that the fume hood will be assembled after it has been made.

Pros for this option include: the cost of manufacturing only needing to cover material costs which is estimated to be $86.54 which is significantly cheaper than the other options. The material used in the fume hood production would be polyethylene which the team has researched and found to be the best material for this application. The design will maintain all of Dr. Lerner's requirements for the project. Cons for this option include the fume hood needing to be assembled after manufacturing which would increase the time before the device is functional. In addition to this the manufacturing may need to be outsourced depending on the resources available through NAU which would increase the cost.

Manufacturing option 3:

The third potential option for our fume hood consists of purchasing a pre-manufactured fume hood from Bel-art. This third option eliminates the need for manufacturing and assembly as the unit comes as one molded fume hood shell. Figure 19 below shows this third option.

Pros for this particular option include: the removal of all manufacturing and assembly processes since the fume hood shell is one large molded unibody, This option includes the rounded pyramidal ceiling that matches the team's designs, and it is made from a durable polyethylene plastic that reduces the risk of corrosion from the harmful effects of carbon fiber. Cons for this option include a price point that is over three times the team's budget. without shipping and tax, this option runs for $1289.55. While this large molded hood matches our required dimensions and weights it does not however meet the requirements for Cfms within the system. This pre-purchased model allows for cfms of up to 350 cfms, recommended. Our exhauster fan runs at 395 cfms and therefore we would be forced to lose 45 cfms to meet compatibility with this option. One additional con of this option is the diameter of the hood stack, our exhauster hose is 4 inches in diameter while the stack is 6 inches, which would then require a reducer to be 3-printed to connect the hose to the stack.

Figure 19.Pre-manufactured fume hood from Belart

1. Design Changes in Second Semester

A manufacturing analysis was performed to determine the best manufacturing process option. To manufacture the option 2 chosen by the client, the team found out that there are three possible options to go with, which are, injection molding, rotational molding, and vacuum molding.

For better manufacturing decisions, there are some considerations that need to be made so the manufacturing process produces the most reliable product. A modified QFD chart presented in Table 4 has been used to determine the best option to go with. The comparison took a place on the device durability, maximum size per part, how many design modifications will need to be made, how tight the tolerances could be made, how much waste material is generated, the cost per part, and the time to fabricate the parts. The values were assigned to each category on a scale of 1,5, and 10. A rating of 1 represents the requirement consideration to be of low value. A rating of 5 represents the requirement consideration to be average worth, and a rating of 10 represents the requirement to be exceeding average.

	Injection mold	Rotational mold	Vacuum Mold
Durability	5	10	1
Cost	5	10	1
Time	10	1	5
Waste generated	5	1	1
Toleranceing	1	10	1
Design ability	5	10	1
Size	1	10	1
SUM	**32**	**52**	**11**

Table 4: Modified QFD Chart

The use of rotational molding is the best manufacturing process for the project as it covers all the benchmarks required and makes modifying the design comparatively simple. This method can be used to make large parts without a reduction in durability or reduction of tolerancing ability. Plus, its ability to create very minimal waste and still be able to accommodate a wide range of designs without a significant increase in cost makes it the best option for fabrication.

When designing a part to be made using rotational molding there are a series of design considerations that need to be made. For our current model, it would need to be modified in such a way to allow for individual parts to be easily replaced in the event of failure or during preventative maintenance, each part should be designed so that it can be made using a singular mold, and the device overall functions should not be impacted by these. Some considerations that need to be made include not using sharp corners, be designed with the flow of molten plastic considered, minimal flat walls or surfaces, and wall thickness being uniform across the individual parts, [15], [16], [17].

2. Design Iteration 1: Change in [subsystem/component] discussion

At the start of the second semester we had a design as can be seen in Figure 20.This design covered all of the customer and engineering requirements that the team had as constraints. After doing research into designing an item for manufacturing it was found that the initial design that the team had would be difficult to manufacture cheaply. The first design change was to break up the device in several parts that can be manufactured individually and then assembled.

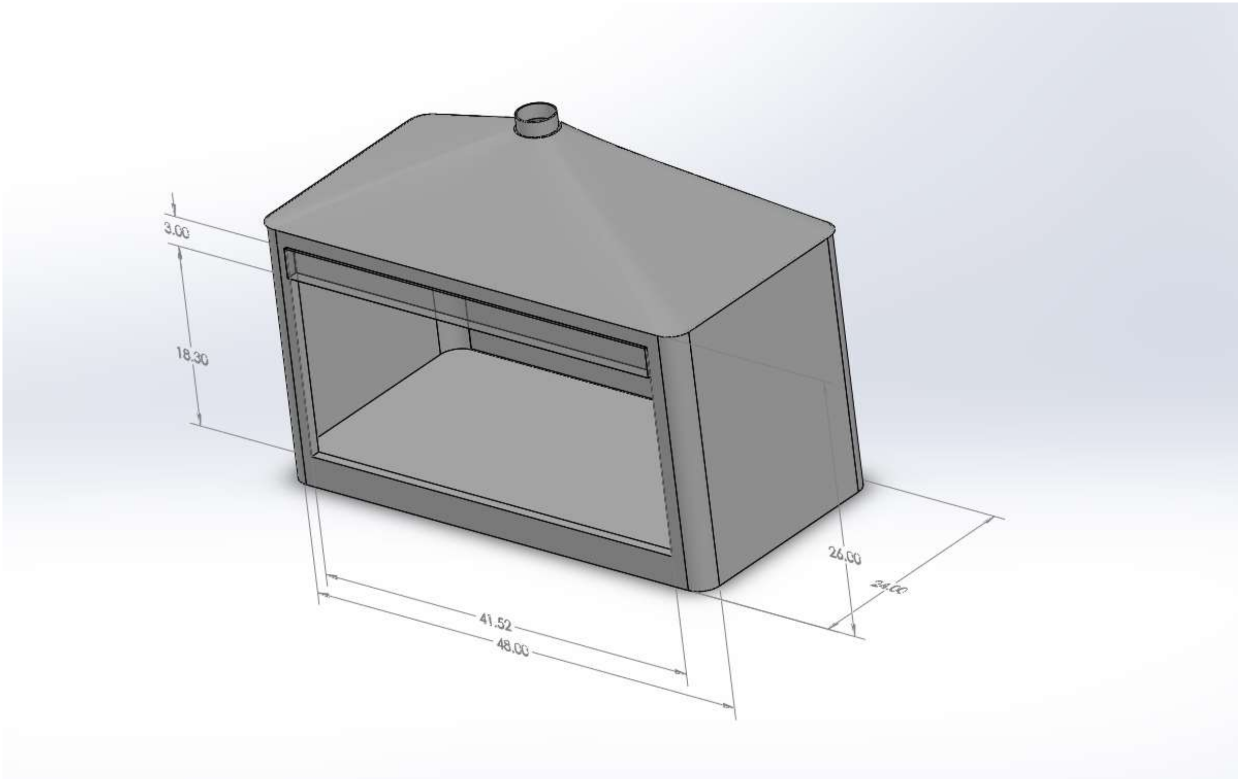


Figure 20. Last Semester Fume Hood Design

The first step was to determine the major sections of the device. The first major section of the device is the bottom floor of the device. This would just be a large rectangular cuboid that served as the foundation for the remaining sections of the device. The next major section is the walls, this will be referenced as the central section. The central section of the device started off as a conglomerate of smaller pieces but after modeling those pieces it was found to be simpler to combine them into a single piece. The last major section of the device is the roof which is where the exhaust port is located. This section is a thin walled pyramid that leads into a cylindrical port. After these sections were determined, the next phase of the design was to determine a way to connect all of the components together. After several iterations of using hardware or pressure fits, the design that was used is a stair like design as can be seen in Figure 20 and Figure 21.

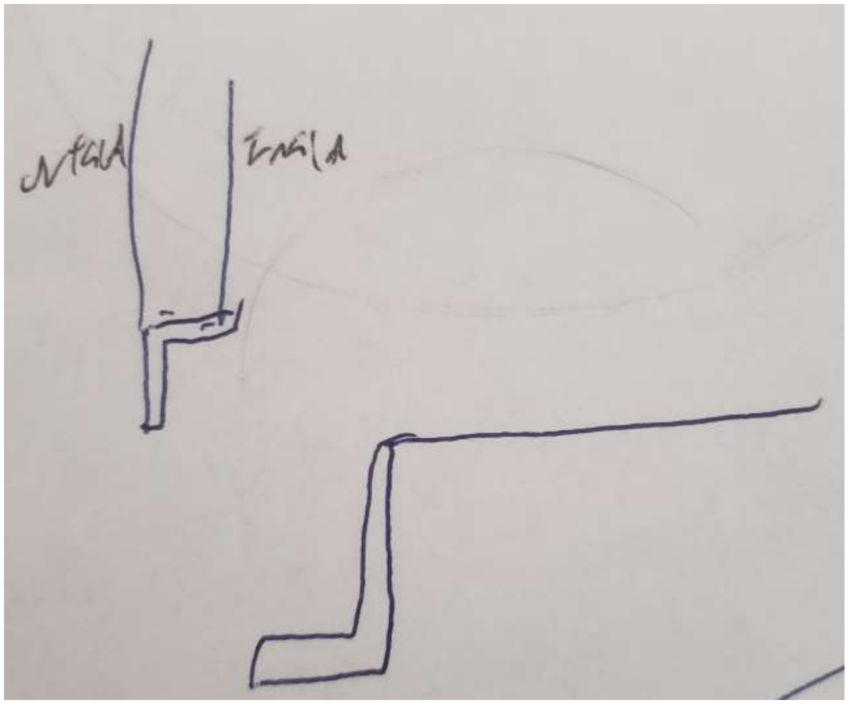


Figure 21. Stair connection

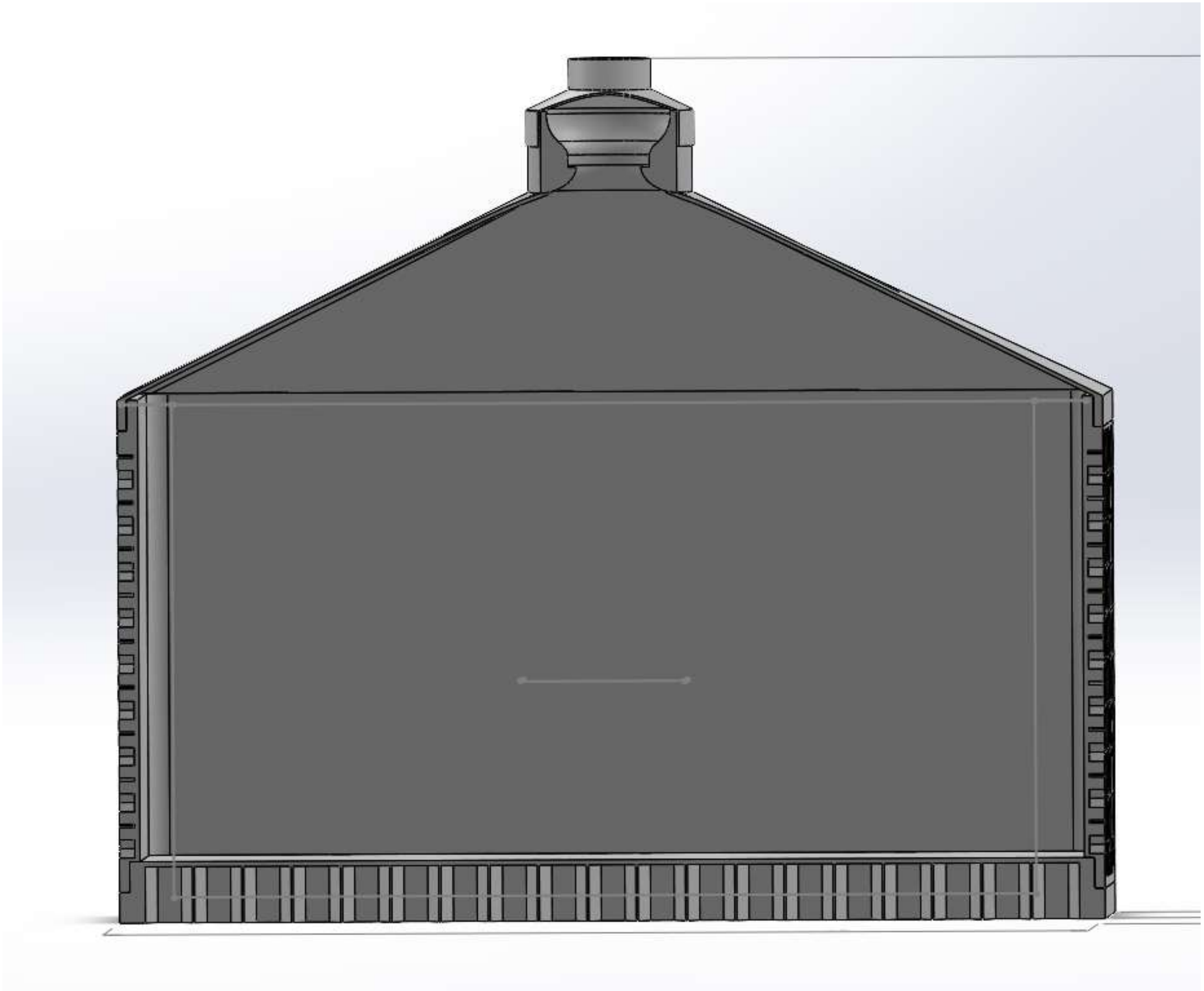
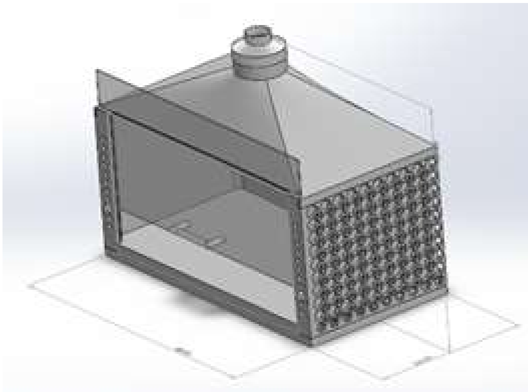


Figure 22. Stair connections demonstrated.

This design was critical for the device as the remainder of the parts and sections were connecting with this in mind. This also simplified the models and allowed for the device to use less parts for assembly. After all of the sections and parts were modeled it was found that the device was much heavier than what Dr. Lerner had requested for the project. After some research was done and various methods were attempted to reduce weight without impacting the performance or structural integrity of the device. Eventually it was found that using a hexagonal latticing across the bottom and central section of the device will reduce its weight without impacting anything. This lattice structure can be seen in Figures 22, 23, and 24.



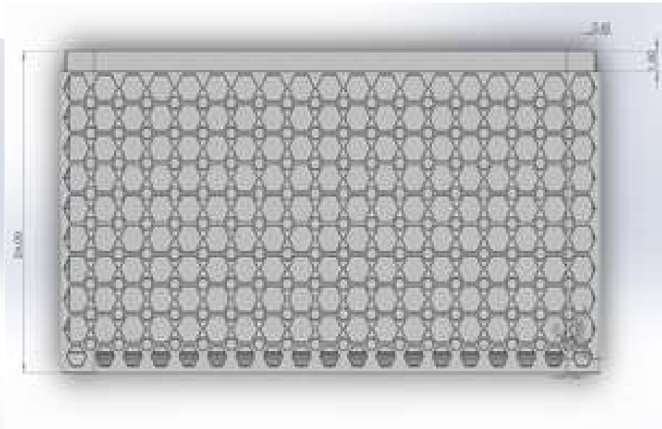


Figure 23. Modified Fume Hood Design Figure 24. Modified Fume Hood Design

2. Manufacturing and Assembly Plan: Fume Hood Manual

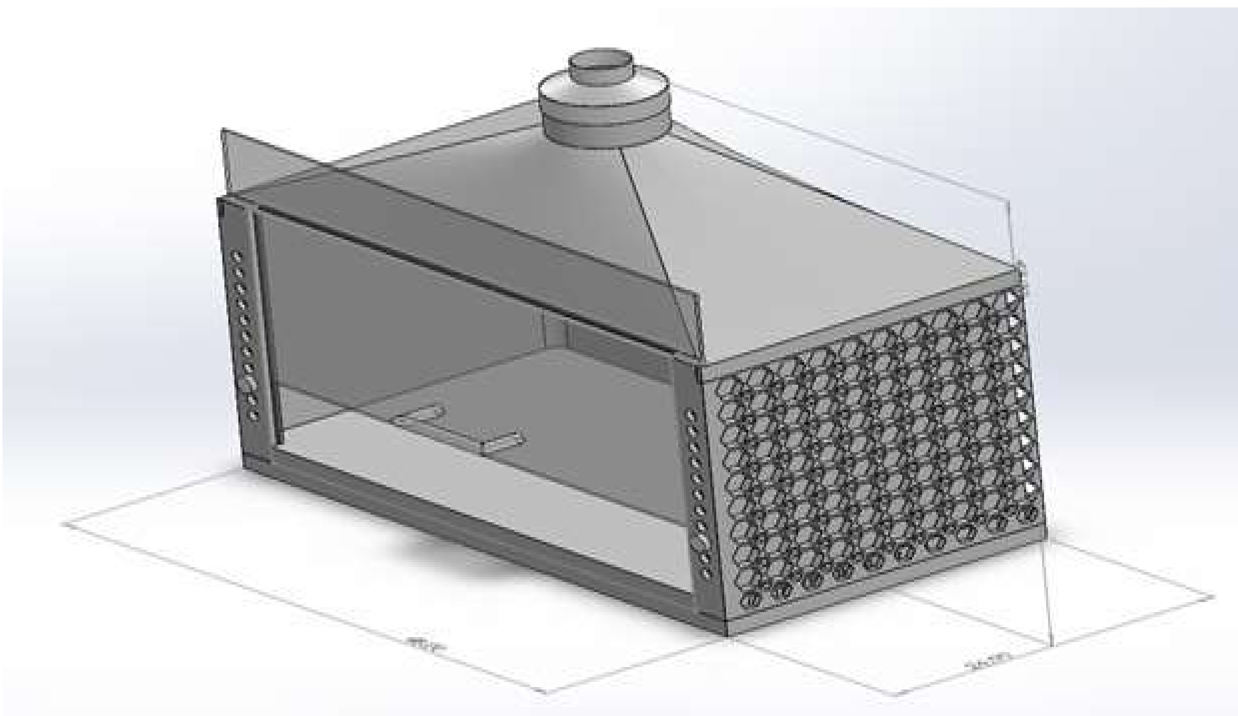


Figure 25.Fume Hood Design

7 Applications

This Fume Hood was designed accordingly to meet Dr. Lerner specification for the Biomechanics lab at Northern Arizona University as a capstone project from Spring 2020 – Summer 2020. It is designed to be used with the EBR-50 exhauster provided by Dr. Lerner the client of this project. This fume hood was designed to neutralize the danger of the carbon fiber particulates and epoxy fumes. HEPA air filter for LEVOIT Purifier LV-H132 is going to be attached in the fume hood to filter the epoxy fumes and carbon fiber particulates.

8 Fume Hood Benefits and Specifications

- Cost of manufacturing and material cost is approximately $600
- Material used is Polyethylene.
- The weight of the entire fume hood including the sash, the reduction cap,

  and the knobs = 115 Pounds
- Differential pressure system.
- LED lights for pressure indications.

9 Filter Benefits and Specifications

- Model: Levoit LV-H132 Air Purifier Replacement Filter.
- Cost: $16.99
- Neutralize 99.97% of dust, pollen, smoke, odor, mold spores, and pet dander.

Last for approximately 6 months

10 Accessory Parts & Dimensions

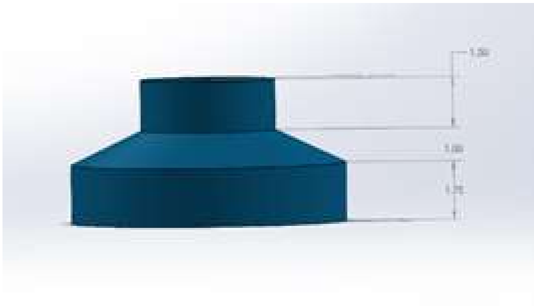


Figure 26 Reduction Cap

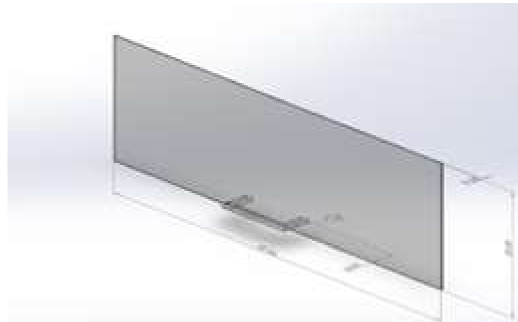


Figure 27 Sash

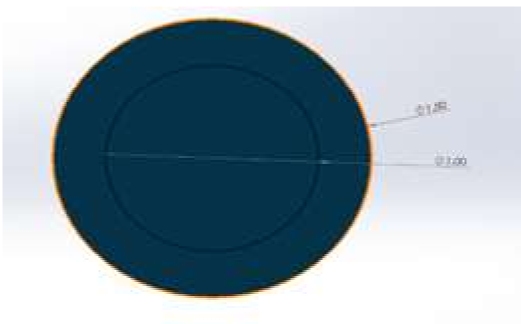


Figure 28 Sash Knob Bottom view

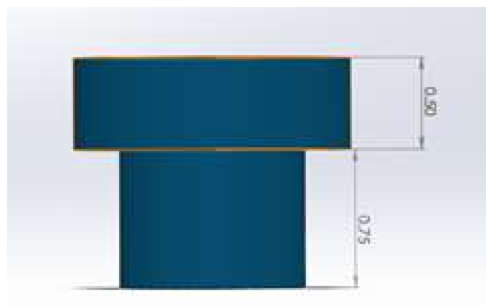


Figure 29 Sash Knob Side View

Figure 30 Central Section

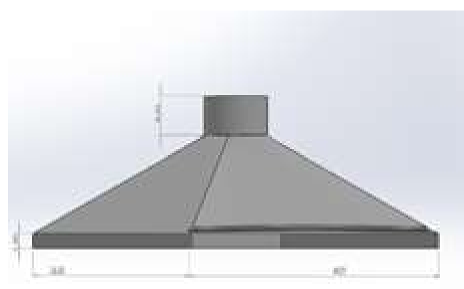
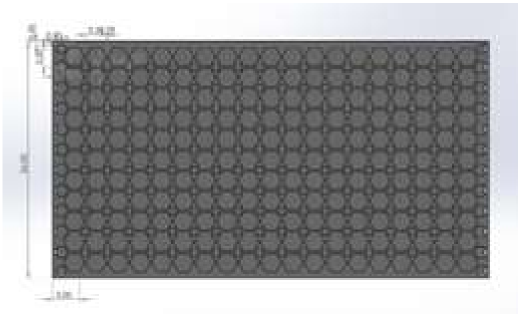


Figure 31 Top section Angle View



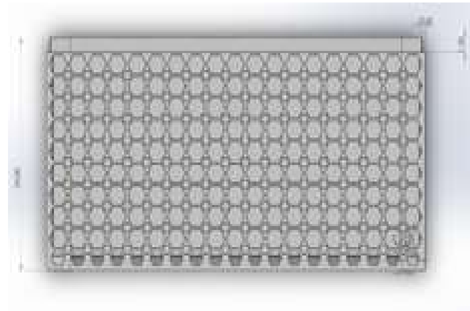
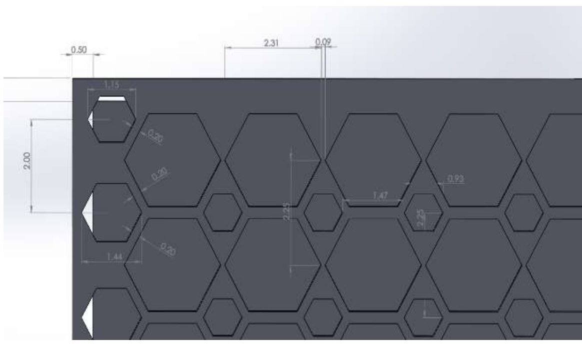


Figure 32 Bottom Section

Figure 33 Central Section Side View



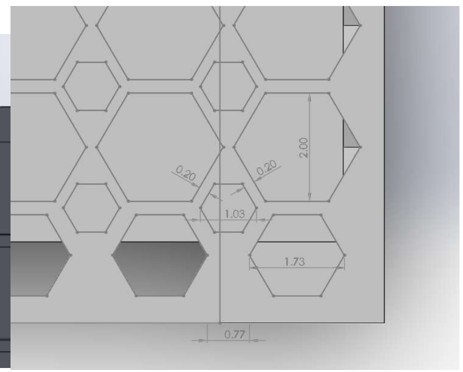


Figure 34 Close up View Bottom Lattice

Figure 35 Zoom Central lattice

11 Assembly Instructions

1. Place the central section on the bottom section and use heat to fuse the parts together.
2. Attach pull handle to polycarbonate sash
3. Slide polycarbonate sash into guide rails on central section
4. place top section on central section and use heat to fuse the parts together
5. place O-ring on exhaust part in the center of the top section
6. place reduction cap over exhaust part and O-ring until seated firmly
7. connect hose from exhaust fan to the top of the reduction cap
8. Lift sash above any of the cut outs on guide rails.
9. Place knobs in the cutout on guide rails to hold the sash in place.

12 Warnings

- Avoiding the assembly instructions could result in a lack of functioning.
- Using a different exhauster than EBR-50 could result in a lack of functioning.

- DO NOT start any experiment without following the device testing instruction that will be discussed and explained in the future testing procedure.

13 RISK ANALYSIS AND MITIGATION

To prevent the risk of potential failures and risks we, as a team identified and expounded on failures from ME 476C. We were able to transmit all potential risks and failures from the first semester of capstone into the final portion of the project. This section will further typify and mitigate all potential failures that the team noted throughout the process.

13.1 Potential Failures Identified Spring Semester

This section will typify the most critical potential failures that we identified in the spring semester of capstone. It was our goal to discover these potential failures and then mitigate them to the best of our ability. We deemed these ten failures to be the most predominant or aggressive within our design. We also will depict the shortened FMEA at the conclusion of this section.

The assembly process introduced in the manual of the device includes fusing the parts together using heat. This process will have the risk of melting some of the fume hood edges, which is going to cause either leakings in the workstation or damage to the parts in a way that they won't function as they are made to be. This failure could also lead to remake the parts again and cost an unnecessary amount of time and money.

13.1.1 Potential Critical Failure 1: Abrasive Wear of Worm Drive Clamp

This potential failure within the fume hood relates to the worm drive clamp that holds the hose onto the fume hood itself. This worm drive clamp provides tension and security to the hose to ensure all particulates and epoxy fumes begin to transfer through the filter. If the worm drive were to fail the hose would detach and particulates and fumes would enter the atmosphere in the room. This failure could be caused by a faulty clamp or excessive vibration on the fume hood which would cause the clamp to come loose. This failure would be remedied by ensuring that the clamp is firmly secured and tightened before using the fume hood system.

13.1.2 Potential Critical Failure 2: Electrical Power Loss from Exhauster Plug

This mechanical failure comes from the necessity for electrical power to operate the exhauster fan. If the electrical plug were to be spliced or otherwise compromised the entire operation would come to a halt. Without the necessary electricity the entire device would be inoperable until the electrical plug was either plugged back in or replaced if broken. This failure is mitigated by properly plugging and unplugging the fume hood when necessary and ensuring that the plug does not come into contact with sharp objects.

13.1.3 Potential Critical Failure 3: Abrasive Wear on the HEPA Filter

The HEPA filter that accompanies our device is quite possibly one of the most important pieces of our entire system. The primary goal of the filter is to capture and retain the carbon fiber particulates that are sucked up through the exhaust hose. Without this filter, particulates would enter into the exhauster fan and cause clogging and internal damage to the blower and the inner workings of the exhaust fan. We determined that abrasive wear would cause the most damage within this system. the sharp edges of the particulates would have a tendency to cut the filter and over time we would begin to see larger and larger rips in the filter, which would allow particulates to escape through the filter and into the exhauster fan. This failure can be mitigated by using a durable filter that reduces the risks for ripping and tearing. We also recommend washing and cleaning the filter on a regular basis.

13.1.4 Potential Critical Failure 4: Plastic Deformation of the Filter Slide

The filter slide is a plastic component that acts as a tray for the filter. This plastic tray holds the filter in place at the bottom of the hose, where it meets the fume hood, and can be easily removed by sliding the tray out and away from the system. This tray allows for easy access and removal of the filter for cleaning and replacing. We examined the potential failures of this tray and determined that it would be susceptible to cracking and deformation due to poor care and maintenance. If the tray were to drop or be inserted incorrectly into the system we foresee the plastic cracking. This would be remedied by using a stronger plastic and ensuring that the users are taking care to correctly remove and re-insert the slide into its housing location.

13.1.5 Potential Critical Failure 5: Abrasive Wear of the Ribbed Exhaust Hose

Our exhaust hose is the means of suction for this device. The characteristic parameters of the hose help to determine the flow rate and face velocity from the exhauster to the hood chamber. The longer the hose the less suction efficiency we would see within the fume hood chamber. If particulates were to escape past the filter they could potentially present a problem for the exhaust hose. The sharp particulates could, over time, rip and tear the hose which would result in velocity, pressure, and flow rate losses within the hose. We plan to mitigate this potential problem by ensuring that the filter is securely tightened and operational. We are also looking into exchanging our current 10 foot ribbed plastic coated air ducting for something stronger. We are looking into a smooth walled hose that resists rips and tears and that also eliminates the ribs.

13.1.6 Potential Critical Failure 6: Thermal Fatigue of the Exhauster Fan

The Exhauster fan is the driving force in this capstone project. Without it we would not be able to successfully meet our design ideas and goals. We determined that one of the biggest potential failures in our design had to do with the exhauster fan and the possibility of overheating. We assume that overheating would occur if the device were to run for many hours a day for consecutive days. Overheating the fan would cause major problems for this system. Overheating has a tendency to cause a very minor degree of permanent damage to the system and over time with additional overheating the device would entirely be considered inoperable. To avoid this probable failure we have designs in place to install an arduino relay system that shuts the power to the fan off when it reaches a certain threshold of temperature. The power would remain off until the device cools down to a safe operating temperature. We still need to further test the theory that a similar system already exists within the fan. In the event that there is no override relay system already in place we plan to install and test our arduino relay system.

13.1.7 Potential Critical Failure 7: Galvanic Corrosion of the Hood Chamber

The hood chamber is, in essence, the box that holds all the particulates and carbon fiber pieces that are being worked on at any given time. This chamber has 3 fully enclosed walls with a 4th partial enclosure on the front. This component gives a workable space in which to safely and successfully extract carbon fiber and epoxy fumes and particulates. This biggest failure to note with respect to this hood chamber is Galvanic Corrosion. Galvanic Corrosion is an electrochemical process that involves two or more metals in contact with one another. In this process one metal (Carbon Fiber) erodes the other metal [15]. Since Carbon Fiber is naturally electrically charged it has an increased chance to errode other materials within this corrosion process. If the fume hood were designed out of something that erodes in contact with carbon fiber our system would be compromised. With this corrosion we would allow toxic fumes and particles to escape through the corrosions and into the open atmosphere which defeats the purpose of the entire system. To mitigate this potential failure we determined some alternative materials to design our hood chamber out of. The best carbon fiber friendly materials are titanium with its alloys or stainless steel. The issue of stainless steel is another type of corrosion [15]. Plastics could also be a viable alternative due to their cost and ease of use.

13.1.8 Potential Critical Failure 8: Abrasive Wear of the Exhauster Fan

We were able to identify a couple of different potential failures within the exhauster fan with our current design and system. We determined that the fan and more specifically the internal blower motor to be susceptible to abrasion wear from particulates. We assume that if particulates were to reach the internal components of the fan that they would lodge themselves in inopportune places in the motor. We assume that tiny particles are not intended to penetrate the inner workings of the fan but would cause issues if they were to penetrate into those areas. To mitigate the risk of these particles entering the motor and clogging the system we plan to ensure that the filter is continually operable without tears and rips which would allow particles to bypass the collection in the filter.

13.1.9 Potential Critical Failure 9: Galvanic Corrosion of the Exhauster Fan

Similar to the abrasive wear of the exhauster fan we can assume that Galvanic Corrosion has the potential to occur within the exhauster blower fan as well. In continuation of the previously mentioned failure (3.1.8) we assume that the filter had already failed thus allowing particles to enter into the inner portions of the blower and causing electrochemical corrosion processes in those regions of the device. This would ultimately, over an extended period of time, render the device useless if the inner workings were to corrode away.

13.1.10 Potential Critical Failure 10: Wear of Arduino Unit Relay Apparatus

The arduino unit relay system is a design idea that would prevent the exhauster fan from overheating and causing damage to the system. This relay system holds the power to exhauster off once the internal temperature reaches and exceeds a safe operating temperature that has been previously set forth by our team. However, there is still the possibility for failure within the relay system. Potential failures for this portion of the system would be normal wear and tear of the unit. If the arduino unit were to be dropped or crushed in any manner it would render the overheating system in-operable. The entire system would still be considered operation ready but would be vulnerable to overheating. This apparatus is intended to prevent other potential failures within the system but also must be analyzed for its own potential failures.

Part # and Functions	Potential Failure Mode	Potential Effect(s) of Failure	Potential Causes and Mechanisms of Failure	RPN	Recommended Action
Filter	Wear	Erratic operation (no suction)	Poor Maintenance (Clogge	2	Remove/clean filter after each use
Filter Slide	Deformation wear (cracking	Poor appearance	Poor maintenance	1	Make sure filter slides with ease into housing
exhaust hose	Abrasive wear	Suction loss (noise,flying debri	Poor Maintenance/design	9	Use a hose with smooth walls instead of ribs
Exhauster	Thermal Fatigue	Erratic operation (no suction)	Overstress (overuse)	16	Do not run exhauster for extended lengths of time
Worm Drive Clamp	Deformation wear	Poor appearance/erratic opera	Assembly Error	5	Ensure worm drive is securely fastened to fume hood
Exhauster Plug	Wear	Erratic operation (no power)	poor maintenance	5	make sure exhauster plug is functionable and safe for operation
Fume Hood Chamber	Deformation Wear	Poor Appearance	Poor maintenance	3	Watch for cracks and deformities in the fume hood
Filter	Abrasive wear	Flying debris/Erratic Operation	thermal deformation from o	7	replace the filter as necessary when signs of wear and tear are observed
Filter Slide	Deformation (thermal)	flying debris/bad appearance	thermal deformation from o	5	replace plastic slide as deformations are observed
Hood Chamber	Galvanic Corrosion	Inability to operate	poor maintenance	10	Ensure carbon Fiber does not corrode the selected fume hood material
Exhauster Fan	Thermal fatigue	Erratic Operation	overstess (overheat)	8	Do not run exhauster for extended periods
HEPA Filter	Wear (Ripping)	Insufficient operation	Durability	2	find a durable filter for carbon fiber use
Export Hose	abrasive wear	suction loss (noise, flying debri	poor design	6	Use a hose with smooth walls instead of ribs
Relay switch	Wear	inability to operate	relay not installed correctly	3	install arduino relay circuitry correctly
blower motor	Thermal Fatigue	Erratic Operation	overheating	16	Do not use exhauster for extended durations
blower motor	Abrasive Wear	Erratic Operation/noise	chipping of fans if particles	24	Ensure the filter safely catches all particles
blower motor	Galvanic Corrosion Wear	Erratic operation/noise	poor filter maintenance	24	Ensure the filter safely catches all particles
Sash Knobs	Wear/ breaking	inability to operate/no sash	poor maintenance/ misuse	4	ensure knobs are built to last
Sash	wear/breaking	no sash/ escaping particles	poor maintenance/ misuse	20	ensure sash is durable and resitive to wear and breaking

Table 5: Updated Spring and Summer FMEA

13.2 Potential Failures Identified Summer Semester

2. Potential Critical Failure 1: Sash knobs abrasive wear/ breaking

One of the potential failures that we discovered in the second semester of capstone dealt with the little sash knobs that holds the sash from collapsing and preventing the operation of the fume hood. The sash is useful in the fact that the it acts as a partial fourth wall enclosure that benefits the suction and extraction of the particulates while maintaining air flow. Potential failures for the sash knobs would be normal wear and tare and breaking. We assume the knobs will be 3D printed to a suitable level that they will be durable and strengthened against the everyday use of the fume hood. If this failure were to occur the severity of the break would be minimal as new knobs can be 3D printed rather quickly and inexpensively within the

Biomechatronics lab. When inoperable the suction efficiency and sash wall would be rendered useless and would prove harmful to the effective capture of particulates.

3. Potential Critical Failure 2: Sash abrasive wear/ breaking

The other side to the sash knobs is the device that they hold in place. The sash acts as a partial fourth wall enclosure that promotes suction and extraction. This thin wall piece of transparent plastic is movable along the y-axis depending on user preference. If the sash were to fail due to abrasive wear or a simple break the device would still be operable, however, it would prove harder to extract and suction particles out of the system since that partial enclosure is not present to promote the extraction process. The sash is easily replaceable and repair time would take seconds.

13.3 Risk Mitigation

Many of these parts/functions depend on the success of the filter. If the filter were to fail in any manner it would make the entire system vulnerable to the harmful effects of carbon fiber and epoxy fumes. If failures within the filter were to be successfully mitigated it would also positively affect the mitigations in the other components as well. As such we focused primarily around the filter and came up with the best solution that we could have in order to mitigate potential failures from that point onward. We determined it best to use a Levoit lv-h132-RF HEPA filter that was able to successfully capture and retain all vacuumed particles. This filter is durable and reusable which helps cut recurring costs from the system. We chose to use a PVC plastic for our primary material selection which help mitigate the potential failures that stem from corrosion. We did not however, have any potential mitigations that made other components harder to accommodate. As stated before, the fume design is rather simplistic in nature and therefore does not demand high risk for any real type of failure. Our final design with our risk mitigated components can be found in the next section of the report. One other format in which to prevent misuse and potential risk and failure would be to provide and ensure that all assembly, manufacture, and operating instructions are followed. Most if not all of the listed potential failures can be reduced if users are careful when operating the fume hood. As mentioned above in section 7.2 new risks were introduced into the project based from the fume hood sash and sash knobs. All other high risk or high importance risks were identified and mitigated in section in the spring semester of capstone as explained in section 7.1

14 ER Proofs

This chapter focuses primarily on the engineering requirements and how they were met between both semesters of capstone. While most engineering requirements have been met there are still a couple that are still in the theoretical stage since conditions were not ideal for most of the project. Some of our engineering requirements had been met based from client feedback and initial conditions while others required testing, 3-D modeling, and analysis.

14.1 ER Proof #1 – [Dimensionality]

This engineering proof determines the dimensionality provided by client specifications. Dr. Lerner asked our team to design, manufacture, test, and implement a fume hood shell that was 4 feet wide by 3 feet tall and 2 feet in depth. This engineering proof was met from the beginning of the design process as it was easy to adhere to this design specification. These dimensions give the user ample room to work safely and comfortably within the system when working with carbon fiber and its particulates.

14.2 ER Proof # 2 – [Fume Hood Shell Weight]

The combined weight of the fume hood shell was constrained to be less than 80 total pounds. This combined weight does not include the exhauster fan. We determined that 80 pounds was an adequate max weight that allowed the user to maintain transportability. We expect the weight to be below the 80-pound limit with a hexagonal pattern that eliminated the need for excess polyethylene fill. This design pattern was illustrated in Solidworks as a part of the manufacturing process. The hexagonal pattern is further illustrated in figure 36.

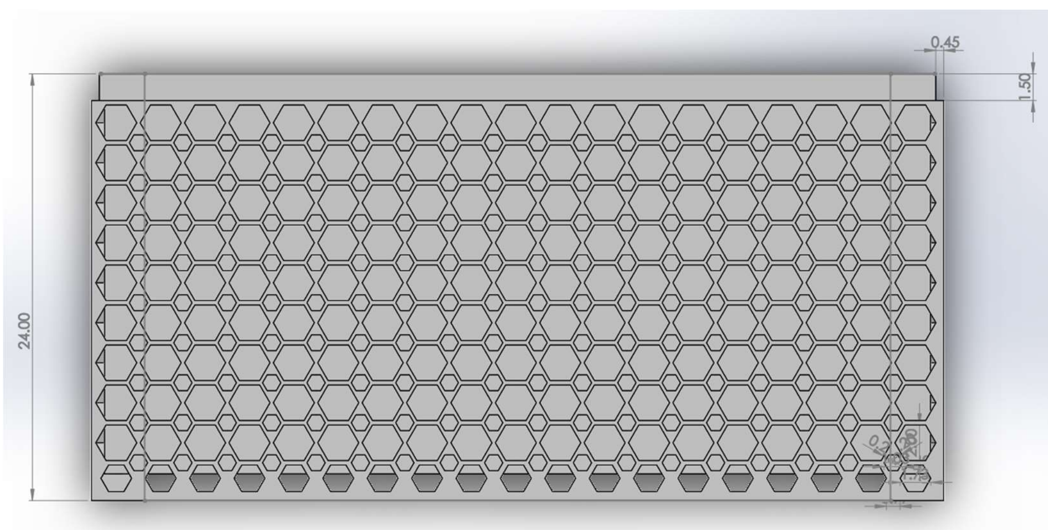


Figure 36: Central siding fume hood shell with hexagonal pattern

14.3 ER Proof # 3 – [Volumetric Flow Rate]

The EBR 50 exhauster fan runs at 395 cfms, optimally. The goal of this engineering requirement is to preserve that cfm number. The cfms drop 5-15 cfms for every additional foot of hose beyond the initial 10 feet. CFMs will also drop between 15-20 cfms for every 90-degree bend in the hose and system [14-EBR manual]. to prevent pressure losses, we maintained the initial 10-foot hose and eliminated any bends and curves within the placement. The only pressure loss that we must be aware of is the loss as the filter begins to collect particles, dirt, dust, and fumes. This loss will be monitored and mitigated through the use of the Arduino pressure sensor system that is mounted on either side of the filter.

14.4 ER Proof # 4 – [Fan Air Velocity]

The exhauster fan manual illustrates that this model of exhauster fan runs with an air velocity of 4000 fpm [14-EBR]. We do not expect this air velocity to be altered or changed. With this assumption we believe that the engineering requirement for air velocity has been met and accounted for.

14.5 ER Proof # 5 – [Pressure Drop]

As mentioned in ER proof #3 the only pressure drop in the system is expected to arise from the filter collecting particles, dust, or dirt. There is no concrete evidence supporting the fact that the pressure drop will increase/decrease in the exact same manner for every cycle. This assumption arises from the knowledge that the collected particles and fumes will not be uniform in dimension and size and will result in varied placement across the filter. Larger particle sizes will result in a smaller pressure drop since the air has more room to move around the filter. The smaller the particle size the more the filter will clog which increases pressure drop. We can expect a range of pressure drops with the expectation that the drops stay in that pre-described range. We expect the pressure drops to be below 2 kPa for every cycle. The Arduino pressure sensor system will monitor the pressure drop and will trigger a replacement light notification when the pressure drops reach a certain point.

14.6 ER Proof # 6 – [Maneuverability]

Engineering proof number 6 relates to the size and weight of the fume hood shell. One on the project constraints, as set forth by Dr. Lerner, is to provide maneuverability within the Biomechatronics laboratory. This includes designing a fume hood shell that is easy to transport while being lightweight enough that one person can move it safely. This requirement was met by implementing a hexagonal pattern on the fume hood shell that reduced overall weight while also using a material that provided substantial grip.

14.7 ER Proof # 7 – [Durability]

The rounded pyramidal design must be structurally sound and must hold up the wear and tare of the sharp carbon fiber particles. We expect a durability rating of up to 200 Kpsi. To meet this engineering requirement, we chose a material that could withstand the everyday use of the fume hood. We chose, in large part, polyethylene as the primary material for its durability and strength. We also required a durable material that eliminated the harmful corrosive effects of carbon fiber. As mentioned throughout the body of this report carbon fiber is a naturally electromagnetically charged metal that often corrodes most other metals. This type of corrosion is termed galvanic corrosion. Polyethylene plastic is resistive to this type of corrosion which proves beneficial to the durability and longevity of the shell.

14.8 ER Proof # 8 – [Filter Assessment in seconds]

One primary goals of our fume hood design team was to implement a pressure sensor device that would read the current filter capacity at any point in time. The results would then display on an LCD screen. To provide efficient data analysis and result we expected the results to give an adequate filter assessment within five seconds. We determined this time to be adequate in terms of filter analysis based on user satisfaction. This engineering requirement will be met in a further testing setting where the device can be built and tested. Due to circumstances surrounding most of our capstone project we were unable to test this assessment along with the pressure device.

14.9 ER Proof # 9 – [Usability]

This engineering requirement proved rather simplistic in nature. The purpose of this engineering proof was to ensure that the pre-purchased EBR exhauster fan was compatible with our final manufactured design. From this knowledge we were able to design around the exhauster fan to ensure compatibility. We implemented a reducer that connects the end of the exhauster hose to the stack on the fume hood shell.

14.10 ER Proof # 10 – [Particulate Capture]

The final engineering proof for this capstone project revolved around efficient and effective particulate capture. We initially expected to capture up to 80% of the filter capacity. This assumed percentage is still theoretical at this point since our team was unable to manufacture and test any component of the device. Further testing will need to be done to determine of 80% capacity is a good mark in changing the filter. One important component in meeting this engineering proof is changing the filter at a percentage that is compatible with a minimal pressure drop. 80% of filter capacity may be too high and therefore further testing would be required.

15 LOOKING FORWARD

15.1 *Future Work*

Manufacturing cost analysis.

A manufacturing cost analysis is needed to ensure whether buying prefabricated parts is better than outsourcing the design to be made and shipped to the client. In addition, after consulting with the head of the machine shop Perry wood, he suggested consulting with specialists on injection molding and vacuum forming to ensure the best assembly quality.

Device manufacturing.

After completing the device testing, the result can affect the manufacturing process of the device. As mentioned in the implementation section of this report, the rotational molding was to apply when manufacturing the parts of the fume hood. If the result of the device testing shows some problems in the type of the manufacturing process, a manufacturing analysis might be done to find a better way to manufacture the device.

15.2 *Future Testing Procedures*

Testing Procedure 1: Adequate Airflow through the Structure

Testing Procedure 1: Objective

The manual should be completed for the assembly of the fume hood structure. Once the physical device is built, the airflow and volumetric flow rate through the structure will need to be tested to identify any stagnation points or leaks. Stagnation points can cause dead zones which can lead to an unsafe accumulation of carbon fiber particulates as the fume hood is being used.

Testing Procedure 1: Resources Required

The resources required to test the airflow through the system include a velocity probe, colored smoke, and the exhauster that will be used throughout normal operation.

Testing Procedure 1: Schedule

The entirety of the testing procedure should take an hour or less. Once all the required testing materials are gathered, the testing can begin.

Step 1 - Test the airflow is to ensure the filter is in place and the exhauster is functioning as it normally will.

Step 2 - Turn the exhauster on and make sure the system components are fully operational.

Step 3 - Introduce the colored smoke to the workspace within the fume hood. The colored smoke should be introduced gradually and at a steady rate to demonstrate the airflow. If any of the smoke escaped, the system has a leak and must be repaired before being considered operational.

Step 4 – Use the velocity probe to search for stagnation points or dead zones. This is done by testing the working space in sections. The velocity probe will be tested initially with the opening sitting at 18 inches.

To test the airflow, the velocity probe will obtain readings from the right to left, horizontally in 6-inch sections. Once each horizontal reading is completed and recorded, return to the initial position, and go into the working space 6 inches. Repeat steps for testing the fume hood horizontally and record each reading.

The goal is to test the air flow in a grid system until the entire working space is tested. Stagnation points will be represented as significant drops in velocity recorded by the anemometer.

Testing Procedure 2: Filtration System

Testing Procedure 2: Objective

The objective of this testing procedure is to ensure the filtration system is operational. This is verified to ensure no carbon fiber particulates are being exhausted into the air. The filter is responsible for collecting the particulates to keep them from causing harmful damage.

Testing Procedure 2: Resources Required

The resources required for this testing procedure include all components for regular use of the laboratory fume hood, fine filtration pads, and a clean HEPA air filter.

Testing Procedure 2: Schedule

The entirety of the testing procedure should take an hour or less. Once all the required testing materials are gathered, the testing can begin.

Step 1 – Turn on the fume hood with all components with the clean HEPA filter. Place the fine filtration pads directly behind the HEPA filter and before the second static pressure tap.

Step 2 – Introduce the carbon fiber particulates produced through the normal sanding operations. Utilize the fume hood as intended for use on a regular basis.

Step 3- Once sanding operations are completed, remove only the fine filtration pads to analyze and determine if there is a noticeable collection of contaminants.

Note * It is considered safe to test with carbon fiber particulates due to the second filtration system. The fine filter pads will collect any contamination coming through the HEPA filer.

16 CONCLUSIONS

This portion of the report concludes with a postmortem conclusion that wraps up the final report and capstone project. This section describes the successes and improvements that the team made and will continue to make as the capstone assignment ends.

16.1 Contributors to Project Success

At the conclusion of our capstone assignment, we are all in agreement that goals and team purpose were effectively met. While there were bumps and unforeseen circumstances along the way, we were ultimately successful in accomplishing our goals and aspirations for the project. While physical and tangible evidence of our work remains unfinished, we were able to efficiently lay the groundwork that will allow Dr. Lerner and his graduate students, or another future capstone team, to finish the final fume hood product. With a more theoretical approach we were able to adequately derive a viable 3D CAD model that will be further tested and implemented into a tangible fume hood when circumstances allow.

Ground rules and coping strategies that were penned at the beginning of ME 476C focused primarily on the respectful and constant communication between all members of the team and client. Equal contribution was also a highly regarded ground rule that was followed by all members of the team. With the shortened summer semester, it was even more pertinent to have each member provide equal contribution. No team is perfect and goes without any sort of miscommunication or effort. While these instances were exceedingly rare, all issues were dealt with in a respectful and positive manner. The team was able to adapt and overcome all obstacles that were placed before them.

With current worldly circumstances it was hard to maintain contact in an efficient and face to face manner. However, with current technology such as cellphones, email, and online shared drives we were able to maintain constant communication. One of the biggest positives of the semester was having the text or script-based communication which we could refer to whenever we so desired. This form of communication helped to register action items and information that was sent back and forth between members of the team, our client, and our faculty advisor Dr. Oman. It was easier to recall that text information instead of just trying to remember what someone had suggested or spoke on. At times however, it was difficult to visualize or even understand some ideas and suggestions that would have been better served in an in-person format.

In terms of positivity and project performance we agree that our time management and quality of work really helped our project. For a portion of the semester we were in a state of limbo as we waited for client verification and validation. Once that information had been successfully conveyed and received, we were able to use our time in an efficient manner which helped to produce the best fume hood device that available. With current circumstances we were able to really focus on the little details that boosted our 3D models, our manufacturing procedures, and our communication and understanding of the problem.

There were very few negative aspects of project performance. In large part, the negative portions stemmed from the lack of in person meetings and understanding. We agree that understanding can be difficult when we weren't all together to discuss and brainstorm ideas and obstacles of the project. It could be hard at times to effectively communicate what one was trying to convey over a text or an email. There is a certain level of understanding and comprehension that eluded us due to the lack of emotion and character that stems from in person meetings.

Of all the information and technology that was available to our team over the course of the semester, the additional help and resources that we received were of the greatest benefit. Additional resources included the input, tips, and suggestions from multiple faculty members from NAU. We received helpful insight from Dr. Trevas, Dr. Baxter, the cline library team, Dr. Oman and so forth that really helped our team succeed in the pursuit of a successful fume hood. As mentioned above, text-based communication also thoroughly helped our team to keep track of ideas, brainstorms, and communication between both first and third parties. It was easy to recollect on new ideas, opinions, and suggestions.

There were no real big problems or issues that the team encountered during the course of the project. Perhaps the biggest setback of the entire project was having to go back to the drawing board halfway through the semester in looking for plausible alternatives to manufacturing a quality fume hood. With Covid-19 we were unable to manufacture, test, and implement our designs and ideas and had to go back and re-think manufacturing and deliverables. We were able to overcome that obstacle and will be able to still provide a quality theoretical fume hood model.

Specific organizational actions such as assignment awareness can be improved upon. The team could have been more proactive in beginning assignments and necessary research and analyses earlier instead of waiting a little bit. Specific technical lessons included the advancement in the understanding of 3D modeling and the many uses that accompany that program. With this theoretical approach we were all able to increase in post collegiate technical aspects that will allow us to perform better in our engineering careers. The concept and understanding of real-life mechanical engineering concepts is perhaps the greatest technical lesson that we can take away from this capstone course.

16.2 Opportunities/areas for improvement

Overall, the team did very well to avoid any type of miscommunication and disrespect. Every effort was made to communicate in a positive and thought-provoking manner. However, there were occasions where respect seemed to have been lost which bordered on violating the team charter and the team goals. With a certain level of uncertainty that surrounded most of the course it was easier to let certain responsibilities slip into a state of idleness. However, our team was able to keep on track with team assignments and personal goals and purposes.

One rule that that the team could have focused on would have been taking advantage of down times. More effort could have been put into assignments and other such goals and strategies that would have resulted in a better section of a report or a more detailed drawing or design. While we waited for client feedback or for a portion of an assignment the team could have focused on other portions of the overall project. Due to the shortened summer semester, assignment deadlines crept up upon us rather quickly which made it hard to juggle everything that was going on at once.

One negative aspect of our project performance was again the inability to create and test a physical model. We conducted all the theoretical testing that we possibly could have but it only carried us so far in our desires in creating the best fume hood that we could have. It was hard to gauge what designs and ideas could work because we were unable to test and validate those designs and implementations. Due to circumstances it proved rather difficult to come together as a team and solve a problem in a hands-on environment where true brainstorming, concept generation, and problem solving are easiest to accomplish.

Being in an online only format proved to be hard in an engineering environment. As engineers we expect to be hands on when solving a problem or working on a project. We felt that our team struggled a bit in this distance learning. We did the best we could with the online tools such as Zoom and google drive but there is no real substitute for the in-person activity that engineers are accustomed to. At times it took an extensive amount of time to receive client feedback to a specific portion of the project that required immediate attention. The methodology of do something and then wait for a response was hurtful to the overall timeline of the team. However, we were able to overcome all obstacles and finished everything in a positive and respectful manner.

The team encountered a few different problems relating to the pressure sensor monitoring systems. With the project being entirely theoretical it was hard to verify and prove that our pressure monitoring system would function in the way it was meant to. There is a lot of guess and checking within that portion of the system that still requires future hands on testing and validation. At one point throughout the project we had a slight issue with the filter being the wrong size. However, through different manufacturing processes and client feedback we were able to implement a solid work around that was compatible with our chosen filter option.

As far as organizational action items are concerned it would have been highly beneficial if the team was more proactive in starting assignments at an earlier date. This action of beginning early would have proved beneficial to the understanding and comprehension of a specific problem and its solution. With an increased zeal for taking responsibility of one's portions of assignments we could have further increased our capacity for understanding fume hoods and their operation. We continued to maintain and organize all shared drives and project assignments.

Additional independent study and analysis would have been something that team could have improved upon. We could have cross trained or analyzed different areas of the fume hood structure that we might not have been as familiar with. Those that were focusing on the Arduino pressure systems could have been more actively involved in the CAD modeling and vice versa as an example. With this cross-training technique, it would have really increased our capacity for good and would be something that we would recommend to upcoming capstone students. Being able to cross train in this regard would have allowed for an increased knowledge of all technical lessons offered in this capstone project.

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18 APPENDICES

18.1 Appendix A: Excessive CAD Modeling Photos and Views

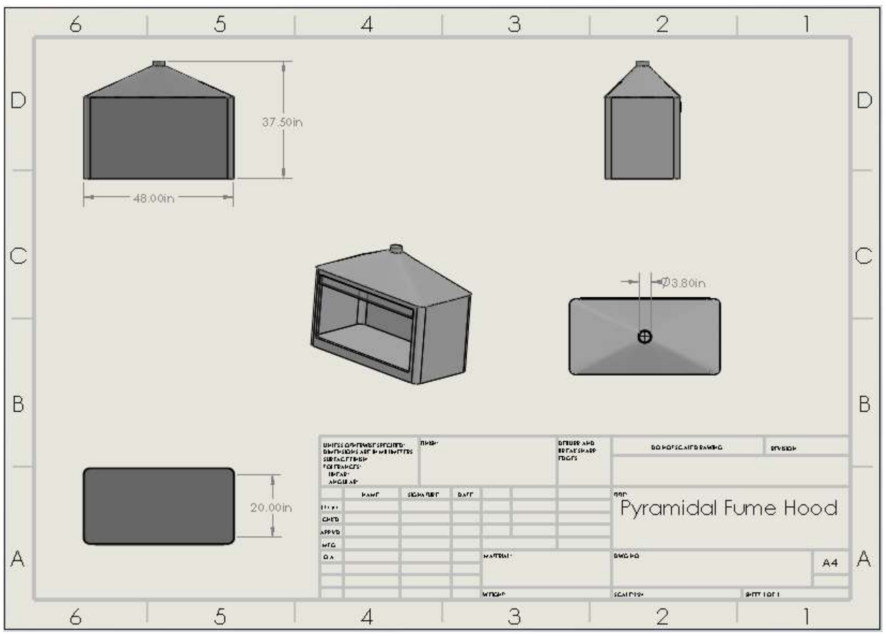

Figure A: ME 476C Final Preliminary Design Assembly View

18.2 Appendix B: Descriptive Title