Laminar Flow Face Shield: Final Design Review
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Abstract

The scope of this project was to design a personal protective equipment (PPE) that protects the wearer from SARS-CoV-2 without inhibiting communication and was comfortable to wear for long periods of time. SARS-CoV-2, commonly known as COVID-19, is a contagious respiratory virus that spreads through droplets produced when someone who is infected by the virus coughs, sneezes, or talks. These droplets may land on the mouths or noses of nearby people or may be inhaled in the lungs, infecting those who come in contact with the virus. The current guidelines to help slow the spread of COVID-19 are to wear a mask that covers the mouth and nose when around others [1]. However, this causes the wearer's voice to be muffled and be difficult to understand, covers the wearer's facial expressions, inhibits others from picking up on important facial cues, and can become uncomfortable after long periods of wear. An alternative that meets these needs would be a powered air purifying respirator (PAPR), which is currently sold by several companies in various forms. Many are quite comfortable and allow the user's face to be seen, but the price is the biggest downfall, most costing over $1,000. Our goal was to design a comfortable, affordable, and effective powered air purifying respirator for Cal Poly professors. We were able to create a respirator that costs only $140, filters out 99.93% of COVID-19 sized particles, and is generally well received in functionality by the general public. This document comprises the results of the critical design process, including background research, specifications, concept development and final design, testing and manufacturing plans, and project timeline.

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1. Introduction

Our team of four graduating mechanical engineering students has taken on a project proposed by Dr. John Chen, a Cal Poly Mechanical Engineering professor. He has identified the need for an affordable, yet effective, personal protective equipment (PPE) device for Cal Poly professors who intend to start teaching in-person classes. Dr. Chen explained that the shield system must be comfortable, self-contained, anti-fog, and provide a steady laminar flow of filtered air to the user, forming a positive pressure environment inside the shield. Additionally, it must be fairly inexpensive so it can be widely available to Cal Poly faculty. Since the device is primarily intended for professors, it is critical that the user's facial expressions and mouth be visible and sound can travel out of the mask, so that communication is not impeded by the shield. More details on the customer needs and wants are provided below, as well as research into current products that meet similar needs.

2. Background

2.1 Technical Research

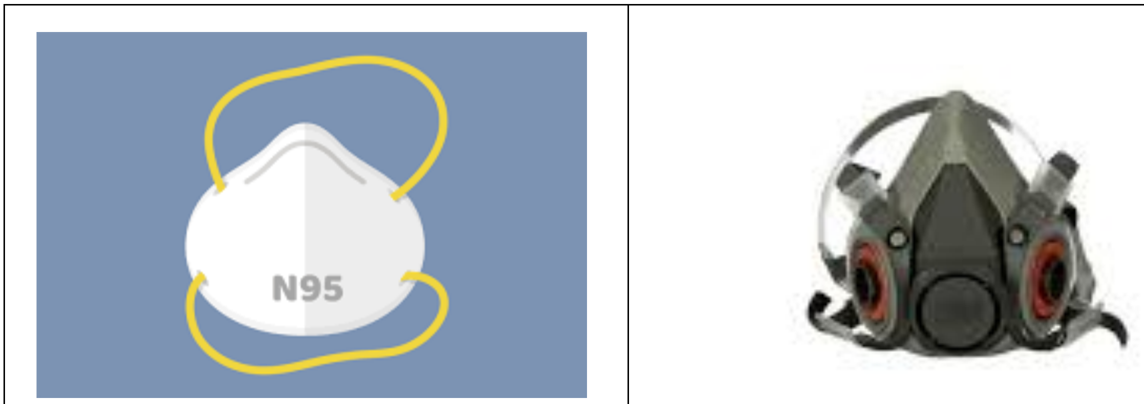
Technical resources were referenced to gather information about the types of respirators, their effectiveness, and specifications on filtration and flow.

Use of powered air-purifying respirators (PAPR) by healthcare workers for preventing highly infectious viral diseases – a systematic review of evidence compiled by Ana Lucina, Andrew Silvers, and Rhona L Stuart provides an excellent description to the various types of respirators used to slow the spread of transmissible viruses [2].

Air-purifying particulate respirators function by removing aerosols from the air through filters, cartridges, or canisters. They can be classified into four groups: (1) filtering facepiece respirator (FFR), (2) elastomeric half facepiece respirator, (3) elastomeric full facepiece respirator, and (4) powered air-purifying respirator (PAPR). This can be seen in Figure 1.

The customer wants and needs were compared with the types of respirators to find a preliminary direction for our project. Because of the positive pressure requirement, the team directed technical research into the effectiveness, method of COVID-19 removal, and deployment of respirators which provided a constant airflow to the user.

The leading regulatory organization for the United States' COVID-19 response, the Center for Disease Control and Prevention (CDC), states that PAPRs reduce the aerosol concentration inhaled by the wearer to at least 1/25th of that in the air, compared to a 1/10th reduction for FFRs and elastomeric half facepiece air-purifying respirators [3]. An assigned protection factor (APF) is used to rate the forms of respiratory protection. All PAPRs must have a National Institute for Occupational Safety and Health (NIOSH) APF of at least 25. For N95 FFR or elastomeric half facepiece respirators, the required APF is only 10 [3].



(1) filtering facepiece respirator

(2) elastomeric half facepiece respirator

(3) elastomeric full facepiece respirator

(4) powered air-purifying respirator

Figure 1. Different types of respirators.

Methods of removing the COVID-19 aerosols and droplets include sterilization, disinfectants, and air purification. Our project scope dictates that air purification is the most suitable manner for COVID-19 removal. The Food and Drug Administration (FDA) lists two types of air purification: (1) filtration, and (2) exposure to UV radiation [4].

A 2020 study, *Far-UVC light (222nm) Efficiently and Safely Inactivates Airborne Human Coronaviruses* found that far UVC light (207-222 nm) inactivates airborne coronaviruses alpha HCoV-229E and beta HCoV-OC43 (used instead of COVID-19 because all coronaviruses are of a similar size). They found that the longer the viruses were exposed to UVC, the more the UVC inactivated the virus. They concluded that ~90% viral inactivation in ~8 minutes of UVC irradiation, 95% in ~ 11 minutes, 99% in ~ 16 minutes and 99.9% inactivation in ~ 25 minutes [5].

The CDC recommended that high-efficiency particulate air (HEPA) filters be used for PAPRs. The Department of Energy defined HEPA filters as 'exhibiting a minimum efficiency of 99.97% when tested with an aerosol of 0.3 μm diameter' [6]. The vast majority of aerosols produced by a human cough are < 1 μm, and SARS-CoV-2 is reported to be 0.06 to 0.14 μm, which falls into a HEPA filter's wide range of filterability [7].

The NIOSH Certification Standards for PAPRs covered the range of acceptable airflows. The minimum airflow rate for a tight-fitting PAPR is a constant 115 liters per minute; a loose-fitting PAPR must provide a minimum of 170 liters per minute [8]. Currently, NIOSH is reviewing a breath-response PAPR, which does not have a constant flow rate; rather its flow rate adjusts to the wearer's breathing rate. A key design flaw for PAPRs is that they do not filter discharge air. Addressing this flaw will be a crucial component of our design.

2.2 Stakeholder Research

As part of our background research, our group decided to interview Cal Poly professors since they will be our main stakeholders. Initially, we only interviewed professors who taught in-person classes, but after a few interviews, we also thought it would be a good idea to interview those who decided to teach online classes due to safety reasons. Interviews were an essential part of our product research because it allowed us to get a better sense of our target stakeholders' perspective.

The first interview conducted was with Dr. Chen, our sponsor. His main requirements for the face mask were the following: safe, anti-fogging, comfortable to wear, allows the wearer's full face to be visible, maintains a positive-pressure environment inside, and most importantly, can be built using easily accessible materials and additive manufacturing. With these initial requirements in mind, we proceeded to interview several other mechanical engineering professors.

There were several common specifications from all the professors: safe, small, compact, good visibility, comfortable for long periods of time, and easily removable for short term needs such as drinking water. A female professor stated that she would like to see a mask with an air-conditioned space and challenged us to design the mask to be gender inclusive. This is an interesting idea to consider, since we want a comfortable temperature for the wearer to be maintained. A male professor mentioned that a face shield should not irritate the ears, and he hopes to see something that could easily be customizable. While the annoyance of mask straps on a wearer's ears would fall into the comfort of the face shield, the product itself could be easily customizable since there are different colored filaments for additive manufacturing. Another professor suggested a face shield with UV protection from the sun. This brought to our attention that our face shield should have good visibility in all types of lighting, including reducing glare in the shield itself.

2.3 Current Market Research

Based off our product background research, we found several items on the market that met similar needs to our problem statement. However, none of the researched products directly met every stakeholder need or want stated above. For example, if the face shield left the user's face visible and provided a comfortable positive-pressure air flowrate, it was well above our target price range. On the other hand, the at-home, DIY powered face shield we found met many of our requirements such as cost, accessibility, and filtration, but lacked in aesthetics and comfort.

Figure 2. 3M Versaflo PAPR TR-300N Kit [9].

One face shield we found readily available on the market was the 3M Versaflo PAPR TR-300N Kit, which contains the helmet with attached face shield, PAPR unit, charging system, and the disposable hood cover. Overall, this PAPR system had very high ratings and seemed to be well liked by the public. On Amazon, this kit received 4.6 out of 5 stars [9]. On Industrial Safety Products (ISP), it received 4.8 out of 5 stars [10]. According to Michael Rivera, on his 2019 blog post titled, *The Best Powered Air Purifying Respirators*, “There really is no better choice for protection against particulates, and despite the full-face protection, it’s even comfortable to use when you’re working in hot, humid conditions." He even claims, "anyone who’s ever used one will tell you that it’s so light when you’re wearing it that you forget it’s even there." This TR-300N system only has one air flowrate, which Rivera finds sufficient even for heavy breathing. The newer model, Versaflo TR-302N+, has an additional higher air flowrate setting, but with the already generous standard setting, it is unnecessary for most applications [11].

All generations of the 3M Versaflo system work in similar ways. Air is sucked up through the opening in the blower pack which sits on the user’s lower back, secured by a waist belt buckle. There is also an alternate shoulder strap that can be purchased to replace the belt. The air is purified through a HEPA filter and pushed up through the tube up the user’s back. It is then dispersed over the top of the user’s head. The air flow path can be seen below in Figure 3 with the red arrows. Additionally, at the bottom of the blower pack, a high-capacity lithium ion battery is attached with a rated life of 8-12 hours, which is above our target of about 6 hours. The system also has a visual and auditory indicator when the battery is at low levels to ensure the PAPR does not unexpectedly stop working.

Figure 3. 3M Versaflo TR-300N diagram.

Clearly, this PAPR system seems to meet many of our most important stakeholder needs, such as comfort, battery life, visibility for the user and of the user's face, but its biggest downfall for our application is the cost. The original price for this entire system is around $1,300, depending on the provider. Since our initial target stakeholders are Cal Poly professors, we are aiming to keep the cost of our design below $200. The 3M filtration unit and battery pack seem to be the most important components. Ideally, we can buy these or a similar product off-the-shelf for our design. However, although these components are a fraction of the cost of the kit, they still cost well above our target price for the shield as a whole. Seeing this, we will need to investigate alternate PAPR units.

Another device we found that met many of our stakeholders' needs was a DIY at-home "Low-Cost Powered Air Purifying Respirator" as described in a YouTube video posted by Johnny Lee and documented on his GitHub page. Lee used a blower, air filter, face shield, face mask from a continuous positive airway pressure (CPAP) machine that he purchased previously, a pair of swimming goggles, and a backpack. Lee also linked a few 3D printable templates for a similar face shield on his GitHub page [12].

While this PAPR machine was much less expensive to build and price was variable based on where each piece was sourced, it failed to meet some of our stakeholders' wants. Most significantly, the comfort of this device was much lower than we were aiming for. A Cal Poly professor would not want to wear tight swimming goggles for a three-hour lab period because of the discomfort this would cause, not to mention the undesirable appearance of the system. Additionally, the user's mouth and much of the face was not visible, which was another important criterion for our stakeholders since it hinders effective communication during class. This PAPR device had many interesting aspects for our application, including accessibility since anyone can purchase the individual parts and make their own low cost PAPR at home.

Figure 4. "Low-Cost Powered Air Purifying Respirator" by Johnny Lee [12].

Another product shown in Figure 5, a welding mask made by Optrel seemed to meet many of the requirements and features we were hoping to implement in our design. The Optrel e3000X PAPR with Clearmaxx Grinding Mask uses a HEPA class three filter that blocks 99.8% of particles and has adjustable levels of airflow. The mask was also one of the few that allowed for the user's face to be nearly completely visible [13]. Although this mask seemed like a great solution to the problem at hand, it costs customers $1,327, which is again above our target price range. We hope to make a product that is similar to this but that is one fifth of the cost.

Figure 5. Optrel e3000X PAPR with Clearmaxx Grinding Mask [13].

Lastly, a concern we acknowledge with all of these researched face shields is the ease of auditory communication between the wearer and another person nearby. Without physically having or purchasing any of these shields to test and try out, it is difficult to know how well the user's voice can travel out of the mask set up, and if surrounding sounds are impeded from parts near the user's ear or noises made from the electrical air blower components. This is something we must keep in mind during our design process and focus on during prototyping and testing.

2.4 Patent Research

While researching, we found several patents for various types of PAPR systems. One that was particularly well documented and informative was for an "integrated belt and Plenum powered air purifying respirator" which was filed in 2015 and reissued in 2018. The patent introduction went through an overview of positive pressure respirators and their effectiveness to guard from harmful respiratory hazards, such as "particulate matter, harmful gases, or vapors, which are removed by passing ambient air through the PAPR" [14]. There were several diagrams at the beginning of the document depicting the belt attachment system and the interface with the user's body. From there, each component was thoroughly explained, which included the hollow belt, filter canister, motor and driven fan assembly, and power source. There were several different possible orientations of the system that were laid out afterward, as well as the communication between each component. The patent research overall gave us a deeper understanding of a PAPR system and the necessary parts to make an effective positive pressure respirator.

2.5 Additional Background Research

We also researched other, more specific aspects of our design, such as the different types of material we may use. In particular, we focused on alternatives for the material that comes into contact with the user's face: the perimeter of the mask and/or any straps used to secure the shield. While the decisions on material ultimately rely heavily on the final design concept and testing, we wanted to get a general idea of the common materials used in this application. Five different types of material were researched and compared: polyester, cotton, nylon, polypropylene, and lycra.

In general, our research found that polyester and polypropylene were the least expensive of the group, followed by lycra [15]. Nylon was the strongest material for this application with a tensile strength of up to 5,500 lbs. per inch width of material. It was much stronger than we needed for our purposes and a waste of budget due to how expensive nylon can be [16]. Cotton was most notable for being easy to sew and good for manufacturing purposes, but it was not all that strong and can be expensive [17]. Lycra, commonly known as spandex or elastane, was extremely stretchy and breathable, but could lose its elasticity over time, limiting the lifetime of our device [18]. Again, our material selection will depend heavily on the ultimate direction of our design, but we wanted to get an idea of common materials we may consider and the pros and cons of each.

3. Objectives

3.1 Problem Statement

Cal Poly professors want an additional piece of respiratory protection so that they can safely and comfortably teach and interact with students in-person since the risk of contracting and spreading illness is too high. The desired requirements for the shield are listed below in Table 1.

Table 1. Customer Needs/Wants.

Category	Specific wants/needs
Human Factors / Ergonomics	• No irritation over long use • Not too tight • Have a mask that doesn’t bother the user’s ears • Make it easy to communicate (talk and hear) • Have reduced glare/good visibility • Must be able to see wearer's face • Won't shift position due to user moving
Geometry	• Something small (Weight and Volume)
Operations	• No fogging up, does not induce sweating • Easily taken on/off for drinking water
Quality Control	• Use optimal materials to ensure highest level of protection to users.
Ease of Use / Accessibility	• Storability (possibly retracting/collapsible) • How do you store it neatly when not in use?
Maintenance	• Reusability for at least 3 months
Energy	• Ventilation system, steady air flow
Transportation	• Ease of transportation
Aesthetics	• something that could possibly be worn in a formal setting • universally acceptable for all users • easy to customize
Materials / Cost	• It is important to buy commercially available materials, for example a face shield, a filter cartridge, etc., for the product to be easily accessible to all • Should cost around $100-200

Currently, most widely available PPE block the user’s face with fabric or other synthetic materials, inhibiting others from picking up on important communication cues, muffles the sound of the speaker's voice, and can cause discomfort after long periods of wear. Additionally, current powered air purifying respirators (PAPRs) that meet the requirements listed above are too expensive.

3.2 Boundary Diagram

In Figure 6, the boundary diagram, a visual representation of what we are trying to design, is shown. The items inside the dotted line are the ones that we can design and modify, while everything outside the dotted line is out of our control. If schools were to reopen soon, we would expect for classrooms to not be at full capacity. However, this still allows for at least 15-20 students to be in a classroom and we would want to keep professors and students safe. The bodies of wearers and surrounding environment are out of our control, but every aspect of the shield, including the fan, tubing, and shield are within our control.

Figure 6. Boundary diagram of respirator.

3.3 QFD House of Quality

With our design specifications in mind, we created a Quality Function Deployment (QFD). We created this to organize our product and clearly define the problem we needed to solve. In this QFD, we were able to establish our stakeholders, determine their needs and wants, rank these requirements by their importance, benchmark our competition to see how our design could be made better, and create an engineering specifications table. The QFD can be found in Appendix A.

3.4 Specifications Table

The engineering specifications table documents how we are going to meet the wants and needs of our customers. The comfort study will be done by asking several individuals to wear our mask and document how comfortable their experience was during their time of use. We will be satisfied once 85% of the users feel like it is comfortable. For the rechargeable battery, we will run multiple tests, leaving the mask on for a minimum of 6 hours and making sure the battery does not run out. For the flowrate, we will measure the flow and make sure it has at least a 115 L/min flow for a closed respirator mask configuration, and 170 L/min for an open mask. These two varieties are discussed more later in this document. These two air flows should be sufficient to maintain a positive pressure inside the mask for the designated configuration based on our research, but this will also be verified in testing. To test the user's ability to be heard, we will have someone wearing the mask, while it is turned on, talk to another person 20 feet away from them and confirm they can be heard and understood sufficiently. This will be done both ways to ensure the mask user can both hear and be heard. To make sure the wearer's whole face can be seen, we will require 80% of the user's face to be uncovered behind the shield. In terms of fogging up from moisture in the exhaled air, we will run simple tests requiring the mask to remain clear even with heavy, humid breath being exhaled inside. We are aiming to keep the application time of the shield for the user below 45 seconds and the daily cleaning time below 2 minutes. In terms of size and weight, we want the mask and all other components to protrude no more than 3 inches away from any part of the body and weigh less than 5 pounds overall. For durability, we expect this mask to last 2 years depending on the frequency of use. For safety reasons, we want the particles per million (PPM) inside the mask to clear 99.5% of all virus. Finally, our target price range is no more than $200, and we want this mask to aesthetically appeal to at least 70% of our potential users.

Table 2. Engineering Specifications Table.

Spec #	Parameter Description	Requirements or Target	Tolerance	Risk	Compliance
1	Comfort Study	85% approval after 3 hours of use	Min.	H	A, T
2	Rechargeable battery	6 hours	Min.	H	A, T
3a	Flowrate, closed respirator (for positive pressure)	115 L/min	Min.	H	A, T
3b	Flowrate, open respirator	170 L/min	Min.	H	A, T
4	Can clearly hear user	20 feet away	±10 feet	L	T, I
5	Can see user's face	80% exposed	Max.	L	S
6	User can hear clearly	20 feet away	±10 feet	L	T, I
7	Anti-fogging	Pass	N/A	M	T, I
8	Cleaning time (daily)	2 min.	±1 min.	L	T
9	Application/removal time	45 sec.	±10 sec.	L	T
10	Size	3 in. off body	±1 in.	M	T, I
11	Weight	5 lbs.	±0.5 lbs.	M	T, I
12	Durability	2 years	±3 months	M	A, T
13	PPM	99.50%	Min.	H	A, T, I
14	Cost	$200	Max.	M	A
15	Appearance survey	70% approval	Min.	L	T, I

As seen on the table, there are risk levels and compliances. Risk levels take into account how important that requirement is towards our final design and are denoted for low (L), medium (M), and high (H). Our high-risk requirements are comfort, battery, flowrate, and PPM. Comfort is important because professors have to wear these masks for hours at a time. We do not want them to get irritated by any of the components. The battery is extremely important because if it stops working, the mask will be useless, and even potentially dangerous, as no air will be blowing into the shield which at the very least can cause unfiltered air to be pulled into the mask, or there is potential for the air flow in to be cut off completely if the seal around the face is tight. On that same note, flowrate and PPM are high risk factors because without sufficient flow in, there won't be a positive pressure in the mask which will allow outside air to enter or restrict the user's breathing. PPM is a measure of how effective the mask is in filtering out the virus which is the main overall purpose of the mask. Compliances are the methods in which we plan to test each requirement: analysis (A), testing (T), similarity to existing designs (S), and inspection (I).

4. Concept

To start off our concept design process, we created a functional decomposition in order to determine the key functions of our system. We began brainstorming for potential solutions for each function and created ideation models in order to visualize our ideas and check their feasibility. Using these models and our background research, we created Pugh matrices in order to determine the optimal ideas within each function. We made a morphological matrix to form eight different, full concept design ideas that combined various aspects from each function. Finally, we used a weighted matrix to choose the optimal design from these eight concepts with which we will move forward.

An important note to be made, at this point in our ideation process an aspect we were aiming to include was filtration of the exhaled air. This function was not an original requirement from our sponsor, and after discussing with Dr. Chen we have decided to remove this aspect from our design. As a team we originally felt this was an important quality of our shield, to not only protect or user, but those around the user. However, this additional requirement was creating several complications, since in order to sufficiently filter the exhaled air, the mask must be completely sealed around the user's face, which was not the goal of our sponsor. If the mask were completely sealed this would also then cause major auditory communication difficulties and potential discomfort to the user. By eliminating this function, we are able to streamline our design and focus on the qualities that our sponsor values: communication, protection for the wearer, and comfort.

You will see below in much of our initial ideation we included features to allow for the exhaled air to be filtered, and while many design qualities from these sketches remain in our current plans the outlet filter is no longer relevant to our design. Additionally, some aspects have actually been reconsidered after removing them initially with the exhaled air requirement, such as the microphone and speaker system, since even without a completely air tight seal around the face, any seal dramatically interferes with auditory communication.

4.1 Concept Development/Ideation and Functional Concept Prototypes

Our first step in the ideation process was to break down the laminar flow face shield into the main functions and subfunctions. We organized our result into the function tree below in Figure 7. Our overall purpose of the face shield is to provide safety from COVID-19, so the key subfunctions listed are necessary for us to consider: provides comfort, make accessible, provide clean air to and from the user consistently, allow clear communication, and interface with head. From there, we further expanded each category into smaller functions. Each of these simpler, more specified, functions helped make the scope of the project feel more manageable, as each one has clear potential solutions and combined together, they should lead to an overall successful system.

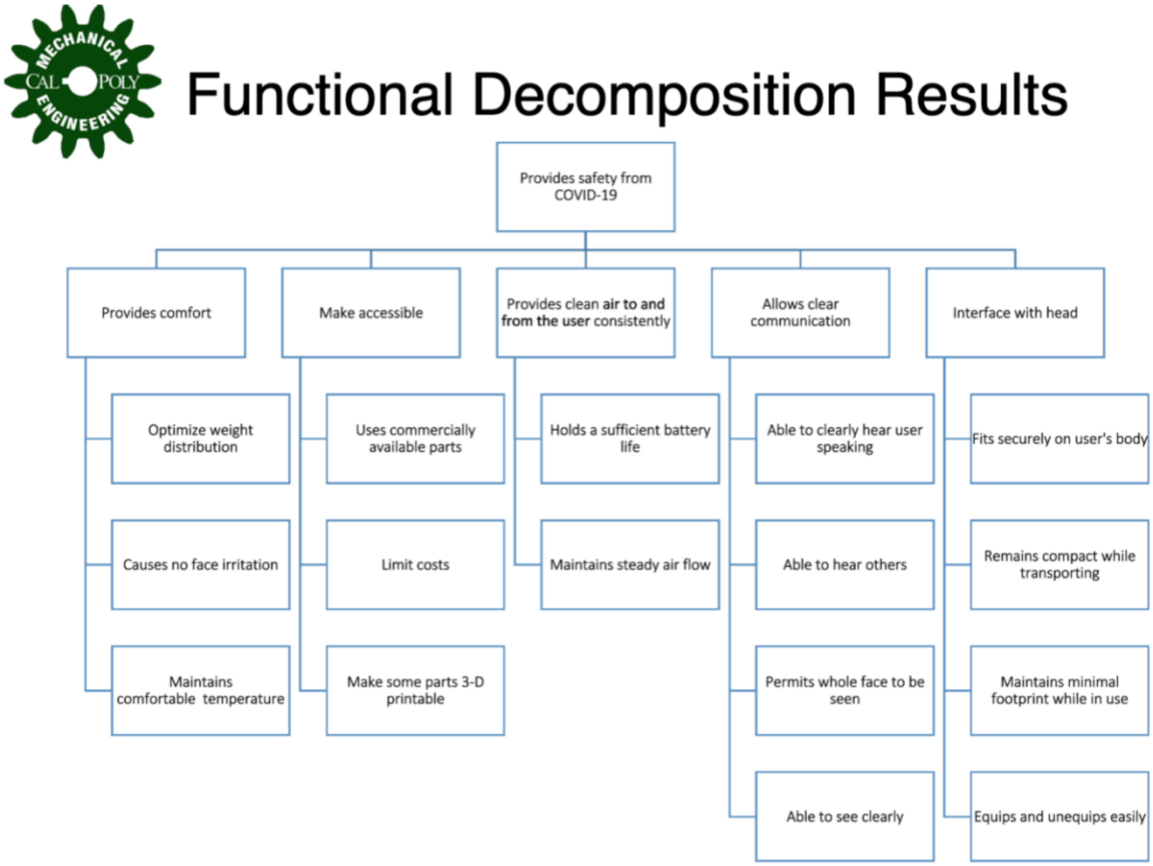


Figure 7. Functional decomposition tree.

With our five key subfunctions in mind, we began the brainstorming process. We conducted three completely separate ideation sessions, each one on different days to optimize our creativity. Our first session consisted primarily of group brain dumping, in which we came up with as many potential solutions to each function as possible, with no regard to price, feasibility, or any other criteria. We followed up the group ideation with an individual ideation session later in the week. During that time, we conducted brainwriting, in which we followed a similar process, but instead each member independently wrote down ideas that came to mind. Lastly, we followed up with one more group brain dumping session to note down any lingering or last-minute ideas. A few notable ideas from this ideation process were the following: detachable, varying-sized face cushions for comfort, a component starter kit and video to support DIY "customers," and adding a Bluetooth microphone inside the shield to enhance communication. A comprehensive list of all our ideas generated during this process can be found in Appendix B.

After creating this exhaustive list of potential solutions, our team went through and removed any which seemed extremely unrealistic. From there, each team member built simple, physical models from this modified list to obtain a better grasp of the feasibility and a visual understanding. Appendix C shows several of these basic prototypes.

4.2 Pugh Matrices

The next step in our concept development process was to organize and compare our remaining ideas in Pugh matrices. The Pugh matrices allowed us to compare all our realistic ideas within each category based on set criteria to identify the optimal choice. To do this, we first needed one idea, or a datum, by which we would compare all alternate ideas of a function. We placed these ideas into columns, and then each row became a criterion obtained from our QFD. After this, we then compared every idea to the datum as objectively as possible, in order to keep our preconceived feelings from affecting the outcome. If the idea was better than the datum for the designated criterion, it would receive a score of a "+", if it was worse it would receive a "-", and if it was around the same it would get the letter "S". After all the comparisons were done, every column was totaled to give a final score. A positive final score meant that the idea was better than the datum and vice versa. This process was conducted seven times total, since we decided to break down the 'comfort' function into 'adjustability' and 'material,' and split up the 'clean air to user' and 'clean air from user' to allow the comparison of ideas to be more valid. These final categories we analyzed in the Pugh matrices were the following: mask material, adjustability, communication, accessibility, clean air to user, clean air from user, and the interface with the body. From this process, we acquired a sense for the best way to address each function. For the most part, the results of each matrix were expected by the group and we moved forward with concept selection using the top two scoring ideas from each category. The Pugh matrices and results are attached in Appendix D.

4.3 Morphological Matrix and Concept Sketches

After finishing our Pugh matrices, we put our top ideas into a morphological matrix in order to generate complete concepts of our face shield models. A morphological matrix works by having every function as a row and putting each different idea as a column in order to choose one idea for each function, which can be seen in Appendix E. In some cases, some functions had multiple ideas implemented into them since these ideas serve different subfunctions within a function. We then generated 8 different complete concepts by choosing at least one solution from each category. As a group, we created one that was the cheapest, one that consisted of only ideas that ranked highest in our Pugh matrices, one that was the most feasible, one that focused only on our customer needs, one on of ease of use and comfort, one on cost and feasibility, one on cost and compatibility, and one on comfort and compatibility.

The first model was our cheapest model. This model had a buckle strap with strategically placed foam to alleviate stress on the person's face. We made the face shield clear but did not add anti-fog or anti-glare, as these features would increase the price. We made the shield non-powered both to filter air in and out which meant there were no needed attachments to hold the battery since it did not have one. This model can be seen below in Figure 8.

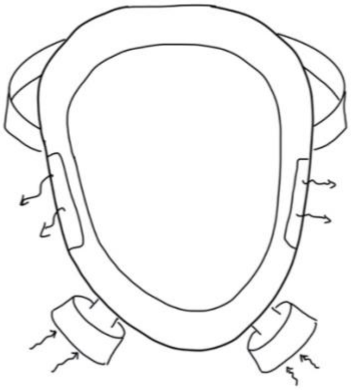


Figure 8. Cheapest design model from morphological matrix.

Our second model was a design that only consisted of each idea that ranked highest in our Pugh matrices. This face shield had different sized, polyester wrapped Velcro attachments for comfort with straps to attach to the face. It is clear, has anti-fog and anti-glare features, and is fully sealed without covering the user's ears. It has HEPA filters powered by a battery with a magnet on the cover that allows the user to attach it wherever they choose to hold the opposing magnet. It also contains side filters inside the mask to filter the user's air to protect others. This model can be seen below in Figure 9.

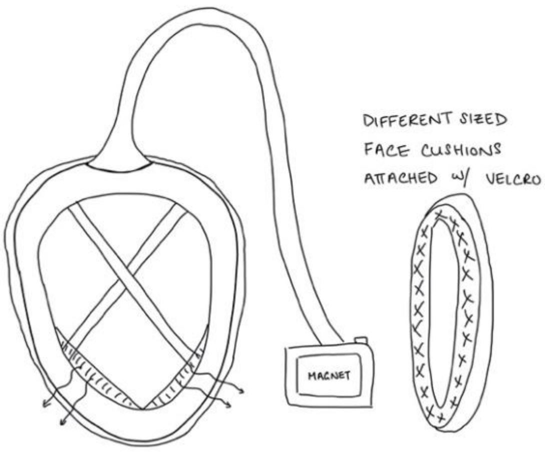


Figure 9. Highest ranked Pugh matrices design model from morphological matrix.

Our third model was the most feasible mask to manufacture. This mask consisted of elastic straps to attach to the head with strategically placed foam pads for comfort with cotton. It was also clear, had the anti-fog, anti-glare features, and did not cover the ears. For filtering air in, we had a tube going in from a battery being held up by a sling on the person's back with a HEPA filter. For filtering air out, we had side filters on the mask. The sling made this system a lot easier to make. This model can be seen below in Figure 10.

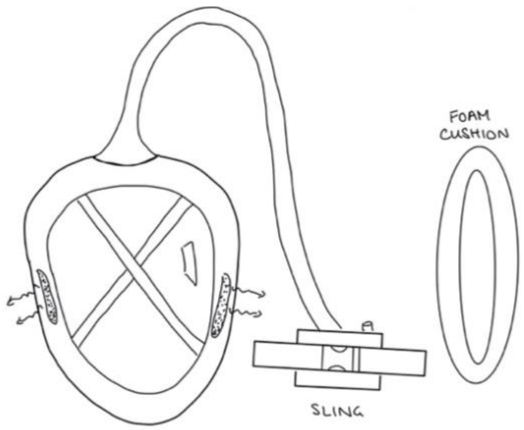


Figure 10. Most feasible design model from morphological matrix.

Our fourth model was made to best fit our customer's needs without our additional ideas. This mask was made out of polypropylene to keep the user fresh from sweat and had a dial knob with different-sized Velcro cushions to put on the mask. Again, it was clear, had anti-fog, had anti-glare, and the mask did not cover up the ears, but we added a microphone and speaker system that would make it easier for the user to communicate with other people. At last, in order to hold up the battery and fan of the filtration system, we used a sling. This model can be seen below in Figure 11.

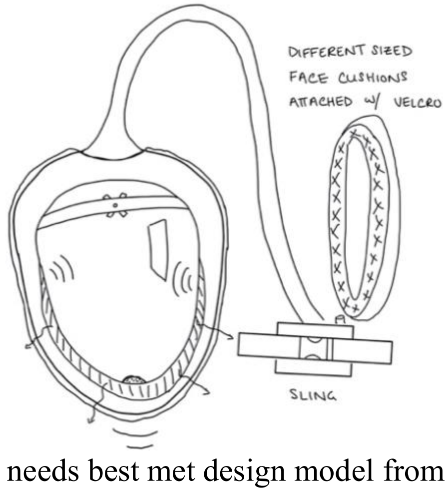


Figure 11. Customer's needs best met design model from morphological matrix.

The next four models were developed by each member of the group and what we each thought was the best option for a full design. Some similarities that we had were that we all had a clear mask, anti-fog, and didn't cover the users' ears.

Peter's design focused on ease of use and comfort. He selected polypropylene because it was a cheap yet cooler option than polyester. He chose an elastic strap because it would be easy to put on and fits all sizes of users. The respirator would not cover the user's ears to ensure the ability to hear. Air would be brought into the mask via a hose attached at the top of the respirator, and air would exit via filters near the chin area of the mask. The interface between the battery pack and the user would be a chest pack, because it was a lightweight, minimalist option. This model can be seen below in Figure 12.

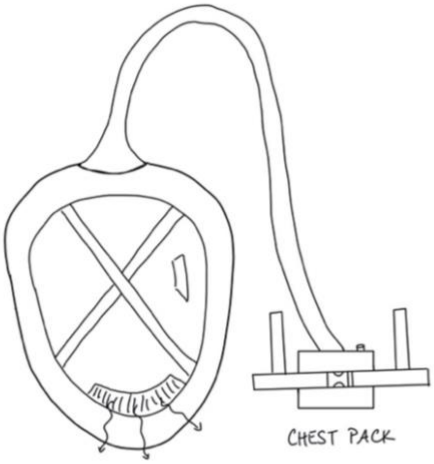


Figure 12. Peter's design model from morphological matrix.

Becky's design focused on optimizing cost efficiency with compatibility. She chose a design with the adjustable dial knob headgear and interchangeable different sized Velcro gasket seals in order to accommodate all user face shapes and sizes. She also chose to include the microphone and speaker option for those who are hard of hearing. Her design was also fully sealed and didn't cover the user's ears for maximum protection while still being able to navigate their surroundings. Air would have been brought in through a tube and pump filtration system and exit through filtered vents on the sides of the face. The battery pack and pump would have been attached to the user via magnets to allow for maximum mobility. This model can be seen below in Figure 13.

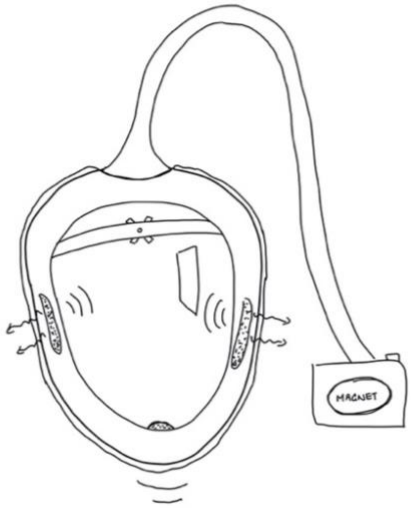


Figure 13. Becky's design model from morphological matrix.

Julia's design emphasized cost and feasibility. She chose polyester which performs well but is still inexpensive to make a simple buckle strap to secure the mask to the head. Julia's design also implemented the simple and sleek belt holster to hold the fan and battery. To ensure comfort was not neglected, she added the differing sized Velcro cushions to the face perimeter and multiple smaller inlet tubes to disperse the air flow over the face. Additionally, like most of the other designs, the anti-fog coating seemed too critical to cut out for the sake of cost, but the anti-glare coating was not added. The same is true for the microphone and speaker system. Julia felt it may be difficult to implement, expensive, and unnecessary for her design. This model can be seen below in Figure 14.

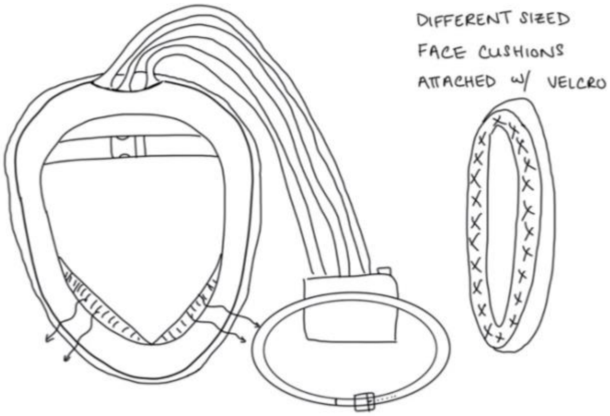


Figure 14. Julia’s design model from morphological matrix.

Jomil’s design focused on all around comfort and compatibility. He used polypropylene to keep the mask cool, elastic straps to make it easy to put it on and take off, and a ring of air with different sized Velcro attachments to keep the stress at a minimal. Since his design was also fully sealed, he added the microphone and speaker system for easy communication. At last, for the filtration system, he used a PAPR to filter air coming to the user and side filters to clean the air coming out. To hold the battery, he decided to create the whole system in a backpack. This way, the user could carry the face shield battery and fan as well as other things that might be needed in their everyday life. This model can be seen below in Figure 15.

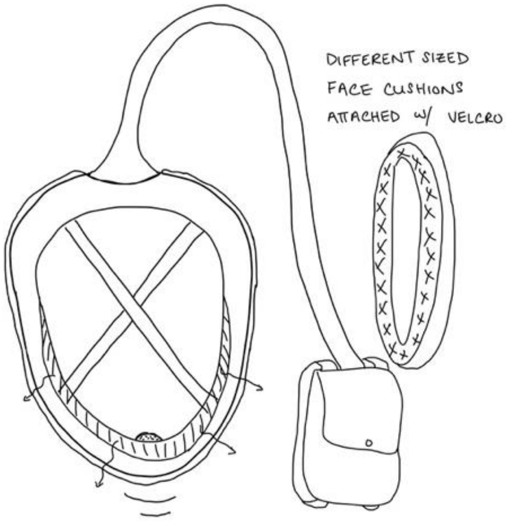


Figure 15. Jomil’s design model from morphological matrix.

4.4 Weighted Decision Matrix

To choose our final design direction, we used a weighted decision matrix. A weighted decision matrix allows you to rank your design by categories and their importance. For our criteria, we used the same ones we used from our QFD along with the score weight we had given them. We put all of our different designs in columns and ranked how well they did for each criterion on a scale of 1-10. These scores were then multiplied by the importance weight and then each design's sum was taken. In order to make this as fair as possible, we all did our own weighted decision matrix and then averaged them all out. The final weighted design matrix can be seen in Appendix F.

After collecting the results, we found that Jomil's design scored the highest due to its high performance in key criteria such as comfort, communication, and visibility. Following Jomil's design were our highest scoring Pugh matrix design, our customer need's design, and Peter's design. After discussing the results, we decided to individually start prototyping Jomil's design. However, after attempting to put together, we found certain features, such as the Velcro attachments and elastic head straps, were not as effective as we initially thought. Instead of using elastic straps, we decided to move forward with a dial knob headgear. The reason for this was that after more background research, a dial knob head gear was a much cheaper and more accessible than we initially perceived.

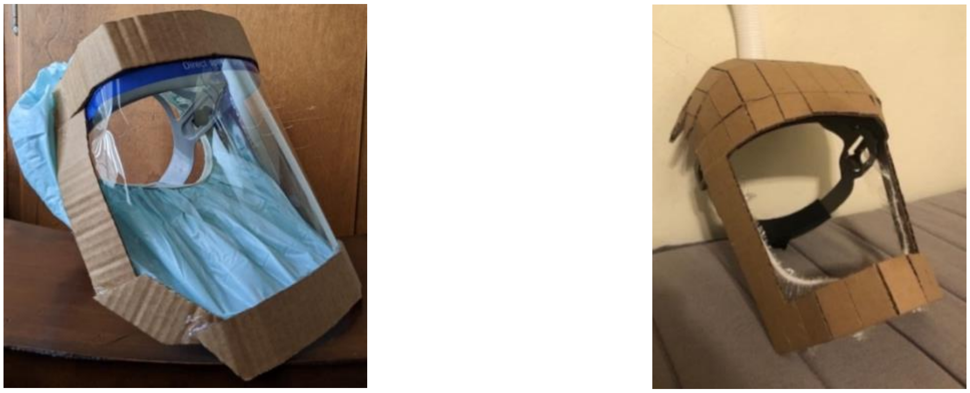
Another note, while much of this ideation process and planning is still relevant to the direction of our design, though continued product research and product selection, our ideas have been altered. This will be discussed further in the document when we explain our final design and the pats we have chosen and why.

4.5 Final Concept Design

The overarching description of the final concept design is a powered air purifying respirator (PAPR) which provides clear communication. Derived from our matrices, the design includes the following highlights:

- **One Size Fits All:** An adjustable helmet secures the respirator on the user's head, flexible elastic material seals the respirator, and a backpack houses the battery pack. The freedom to adjust the fit to one's head increases the comfort of our design.
- **Clear Communication:** Respirator does not cover user's ears, and the fan is placed on the users back to minimize its impact on hearing and speaking.
- **Positive Pressure:** Achieved by constant airflow to respirator, and respirator being sealed.
- **Distributed Airflow:** To spread flow across user's face, a funnel shaped outlet is placed at the user's forehead. The airflow also provides relief from heat-related issues, like fogging and sweating, which boost our design's level of communication and comfort.
- **Inlet-Filtration:** A fan/blower sucks in air, which is then filtered and supplied to user. Vents located near the user's mouth release exhaust air.
- **At-Home Manufacturability** – Our design takes into consideration that all components need to be commercially available or easily manufactured with readily available materials. We intended to utilize off the shelf parts for the bulk of our product, and 3D print the remaining connections between this parts.

Instead of building a single concept prototype, we decided to individually build a prototype. Because of the virtual setting of this course, we decided that constructing our own prototypes would allow us to better understand the product we wished to design. The concept prototypes can be seen in Figure 16. The backpack is not included with the concept prototypes photos; please note that it has been modeled in the concept prototype as being located at the end of the hose.



Becky's Prototype

Peter's Prototype

Julia's Prototype

Jomil's Prototype

Figure 16. Concept prototypes.

While different in appearance, the prototypes all modeled the same system. An assembly of the respirator system was built using SolidWorks, drawing from some of the specific characteristics of each design. See Figure 17 below.

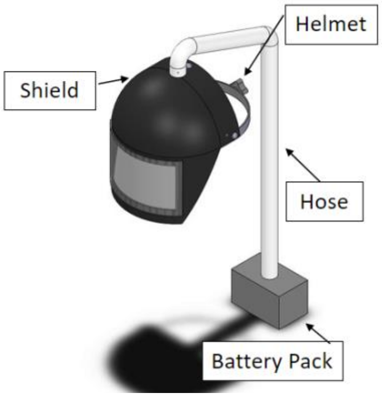
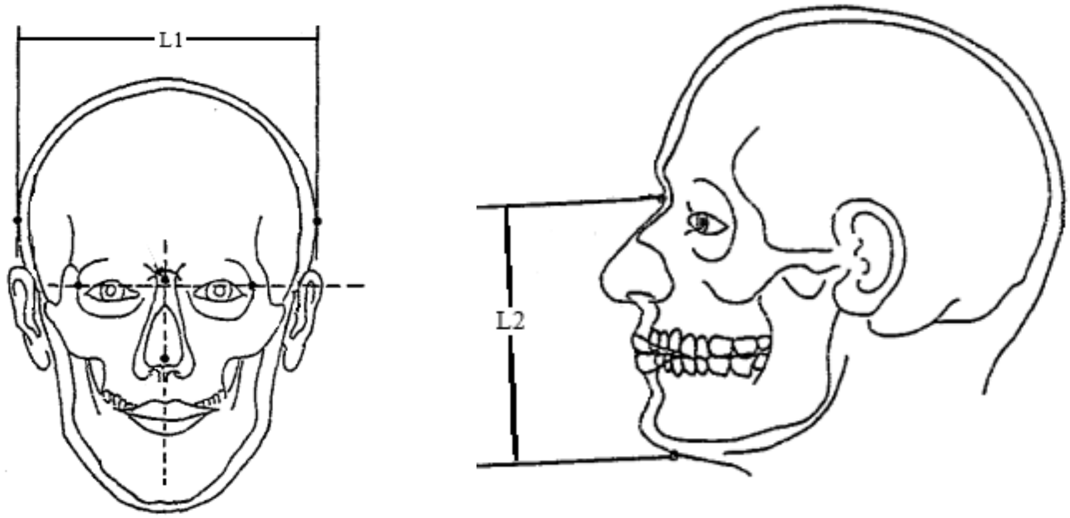


Figure 17. Isometric view of CAD assembly.

The design functions when the fan, located in the battery pack, sucks air through a set of filters. The filtered air flows through a flexible hose and into the helmet piece of the respirator. A part inside the helmet switches the hoses' circular cross section to a geometry which provides a wider range of flow over the users' face. Finally, the air works its way out of the respirator by passing through the exhaust valves near the user's chin.

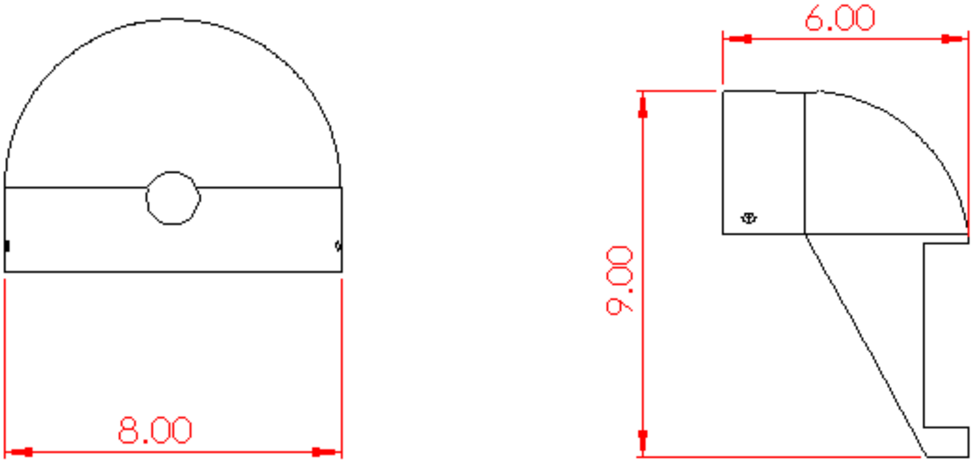
All the prototypes aimed to produce the same product, yet it was evident that there was a difference in the geometries, materials, and the way they were built. Each of the concept prototypes were built to scale yet having a baseline for dimensions still resulted in a difference in sizes across the prototypes. The difference in geometries was acceptable for the components of the design that were meant to be adjustable, such as the headgear and the elastic material used to seal the respirator. However, the dimensions of the rigid shield part needed to be standardized. The geometry of this part was standardized by anthropometric data [19]. The rigid shield was meant to be of a single size; thus, dimensions were decided on as being the average of 50th percentile for males and females, seen in Figure 18. The average measurements were 6.00 inches for head breadth, and 4.5 inches for Menton-Sellion length.



Head Breadth, L_1 Menton-Sellion Length, L_2

Figure 18. Standardized dimensions for the rigid face shield part.

In combination with the anthropometric data, the shield's dimensions were also bound by the print volume of 3D printers. We have access to a 3D printer whose print volume is 8x8x9 cubic inches, so this volume was what the shield was designed for. The final volumetric dimensions of the shield can be as seen in Figure 19.



Top View

Right View

Figure 19. Standardized dimensions for the rigid face shield part. All dimensions are in inches.

The materials used to construct the concept prototype were significantly different from the materials we expect to build the final product with. However, the functionality of several of the materials used to construct the prototype will be crucial in determining the materials for the final product. All of the concept prototypes utilized the same knob-adjustable helmet piece. It provided a place to seat the rigid face shield and was adjustable, which met our design specification of a 'one size fits all' design. Another commonly used item was the disposable shower caps, used to simulate the elastic sealing material. The shower caps were an accurate model of the function we desired for the flexible elastic seal.

In building our concept designs, it was concluded that there were several important manufacturing ideas that can be incorporated into the manufacturing process for the final product. Being able to build the respirator at home was one of our design goals; the lessons learned from prototyping are directly applicable to the manufacturing of the final product. It was readily apparent that we will need to develop a bill of materials and assembly instructions to ensure that each product will be built as designed and, therefore, function as designed. Most prototypes struggled with applying the shower caps to the rigid face shield part. In the future, we will need to find a method of meshing the two items such that a seal is formed. Initially, we planned to 3D print the face shield perimeter and use commercially available clear visor plastic, but this plan has been altered since this point in our design process. We now have a single, off the shelf complete face shield , which significantly minimizes the component numbers.

There are multiple undefined parts of conceptual prototype; most can be resolved with testing. First, regarding the airflow: How will we design a part that provides a wide range of airflow over the user's face while maintaining laminar flow? What is the most effective and comfortable orientation of the shield and inlet air tubing? These questions can be answered as we progress in our project and get to the testing phase. Another line of uncertainty revolves around the fan/blower and battery pack. To choose the right ones, we will need to find the optimal airflow, and then consider various sizes. The sound of the fan/blower may impede communication; it will be important to choose a quiet machine. The fan will also have to be exposed to air, meaning that we will need to design a custom backpack or customize a commercially available one. The battery is reliant of the fan/blower selected; important characteristics of it are its weight, size, and life. Finally, testing will need to be conducted on the volume of the user's voice while wearing the respirator. In the scenario that it is necessary to amplify the user's voice, it has been proposed that a microphone is inserted into the respirator, and then paired to an external speaker.

4.6 Preliminary Design Risks and Concerns

Prior to testing and manufacturing our product, our team contemplated the risks associated with the use of our face shield. The main risks we foresaw was a possible malfunction of the pump while the face shield was in use or the battery dying, causing the user to lose air circulation and have a hard time breathing. Some preventative measures for such an event would be to extensively test the motors, pumps, and batteries chosen for the face shield in order to ensure reliability and to have reminders in the packaging to always bring a backup face covering to switch into. The design hazards checklist may be found in Appendix N.

A number of concerns arose while we were deliberating our risks. Our first concern was if our design using a flexible elastic material to seal off the face shield from outside contaminants was a suitable seal. Another concern was how well we would be able to filter the user's output air. Lastly, how we would achieve the optimal airflow rate in the face shield. These concerns can only be addressed through the testing phase.

5. Final Designs

As noted above, we went through several iterations of shield configuration. Initially, our intention was to have a completely sealed mask around the user's face and filter the inlet and outlet air. After discussion with our sponsor and as a team, we have decided to remove filtering the outlet air for the sake of feasibility and communication. A main point of difficulty was balancing the importance of safety versus communication. With an unsealed mask, safety is put into question because there is a potential for unfiltered air particles to make their way into the breathing path from under the user's chin or sides of the face if the air flow rate in is not high enough to maintain a positive pressure. Additionally, maintaining a positive pressure inside an open mask is significantly more difficult compared to a sealed mask. On the other hand, a sealed off mask creates difficulties for effective auditory communication. The more sealed the mask is, the less sound can travel out, such as the user's voice.

With this in mind and after continued discussion with our sponsor, we are moving forward with two varying mask designs: one focused on safety, and the other focused on effective communication. The two final designs we chose to move forward with were: a fully sealed mask and a completely open mask. Both of these masks were designed to work with the same filtered blower system that would deliver filtered air to the user. The intention is to determine the optimal mask configuration through planned testing and either narrow our final design to one mask, or complete both setups and allow the user to decided which mask to use based off his/her needs.

5.1 Final Designs Specifications

There were three main subsystems to the design: the battery pack, the hose and attachments, and the mask. Figures 20, 21, and 22 display the design and its components.

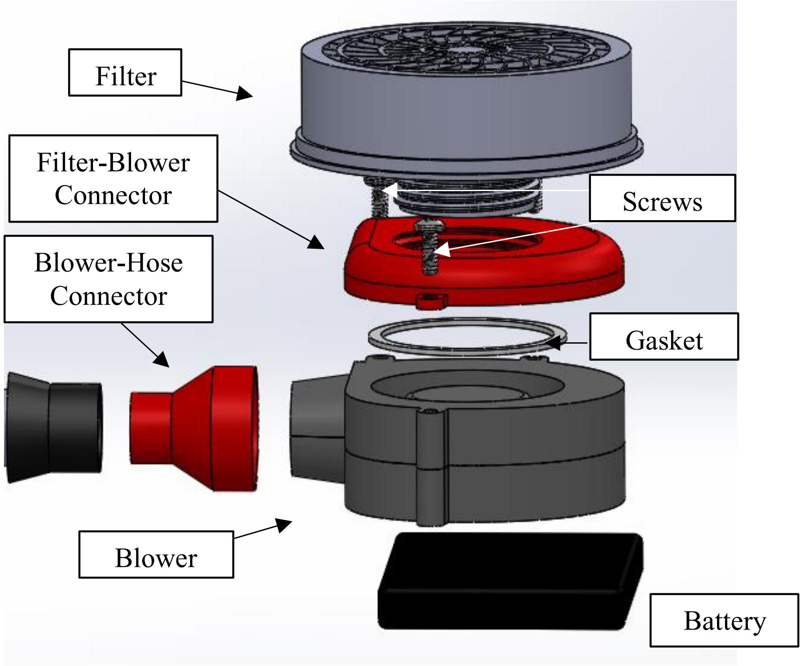


Figure 20. Exploded view of battery pack subsystem.

The battery pack subsystem (Figure 20) included:

Battery: The power supply will be connected to the blower. It will be rechargeable and last at least 6 hours of use when at max power.

Filter: The filter is connected to the blower's inlet opening via a custom 3D printed connector and gasket for a leak-proof connection.

Blower: The blower filters outside air by sucking air through the filter and pushes it through the hose to be distributed through the mask.

Filter-Blower Connector: 3D printed connection with threads to screw into the filter and holes to allow fastening to the blower.

Blower-Hose Connector: 3D printed connection from the blower outlet to the hose.

Screws: Three #10-24 x ½ screws used to fasten the filter-blower connector to the blower.

Housing (not pictured): All the previous components will be attached in a custom 3D printed housing to allow for easy transport and to protect the components. The housing may be attached to articles of clothing or bag straps via belt clips.

The hose subsystem includes:

Hose: The flexible hose carries the filtered air from the blower to the mask. It has a 1" rubber connection at each end.

The two subsystems listed above will remain the same for both designs. The mask subsystem will be broken into two different designs.

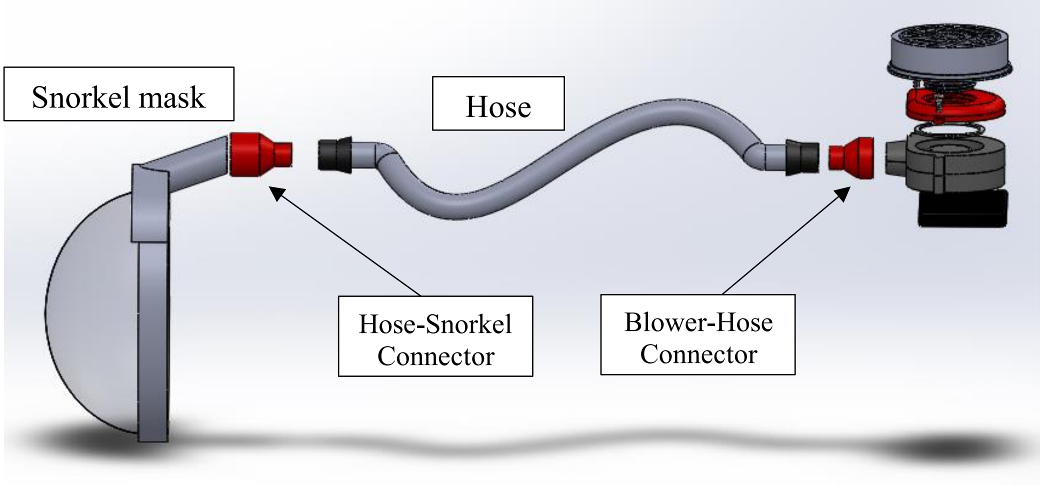


Figure 21. Sealed design configuration.

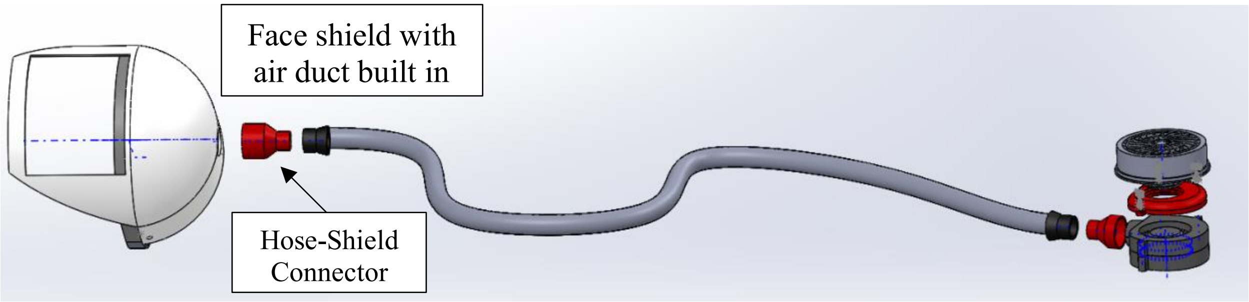


Figure 22. Open design configuration.

The fully sealed mask (Figure 21) included:

- **Snorkel mask:** This mask creates a complete seal around the user's face, preventing contaminated virus particles from being inhaled. The scuba mask also contains an inlet fixture that allowed us to easily attach the hose.
- **Hose-Snorkel Connector:** 3D printed connection between the hose and snorkel.

The open mask (Figure 22) included:

- **Face shield:** The face shield will act as a barrier between the user and oncoming droplets that could potentially be inhaled.
- **Air hose duct:** The air hose duct sits at the top of the face shield, sealing the shield to the top of the user's face. This ensures that the filtered air coming from the hose is not contaminated by the time it exits the duct. It also ensures that the airflow exiting the duct does not pull in unfiltered air into the shield from the surrounding area.

- **Hose-Shield Connector:** 3D printed connection between the hose and snorkel. It will be different from the fully-sealed hose-snorkel connector because of the air duct inlet's geometry.

Our design will take in air from the surroundings using a blower. The air will pass through a filter that is connected to blower's inlet. The filtered air will then pass through a hose that is connected to the face shield at a flowrate of 115 L/min for the sealed mask and 170 L/min for the open mask. These values were obtained through research with the CDC and are our starting values. They will be reevaluated through testing. The air supply will also eliminate possible fogging due to the user's breath.

5.2 Prototype Analysis

The completely sealed mask design will meet most of our specifications due to preliminary prototype tests that were run and the similarity of the design to already existing designs. The main concern was the compatibility of the parts since our components are coming from numerous various vendors. When building our structural prototype, we found that the compatibility of the components was not a significant hindrance to our design, especially since we 3D printed our connector components giving us flexibility with the geometry and size. When testing the blower, a power supply was used to find the proper output needed to power the blower for 6-hour intervals. We were able to loosely assemble the components and test the flowrate of the mask, finding that even though there was air leaking out of the parts due to initial improper fitting connections, the wearer still felt a comfortable flow of air while the device was running. A propellor anemometer was used to find numerical readings of the air flowrate at the blower outlet, with the filter secured over the inlet of the blower, but these readings fluctuated immensely. While testing, we also found that the user could clearly hear their surroundings, more than 80% of the user's face could be seen while the mask was on, and the mask was anti-fogging. When the device was turned off, the user experienced the clear shield piece fogging immediately due to their breath. Once the mask was turned on, the fogging was cleared from the flowing air. Application and removal time also met the specification of 45 seconds. The snorkel mask that was purchased included clips on the bottom portion of the straps of the headpiece. These clips allowed for the mask to be put on and taken off without much effort. From our structural prototype, weight requirements for the sealed design were met with the battery pack weighing three and a half pounds. The filter we purchased was rated to filter 99.97% of particles per million, which was the recommended CDC specification for PAPR's. Now that the compatibility of the design has been analyzed, we will be focusing on further testing for safety and usability.

Figure 23. Sealed design structural prototype. From left: the assembly, the battery pack subassembly, and the prototype in use

5.2.1. Prototype Findings and Conclusion

Since the majority of the design between our open and closed face respirators was the same, we switched our closed snorkel mask with our open-face shield in our prototype to see how it would perform. To our surprise, the communication between the open and closed face shields was very similar. Both shields muffled the communication from the user, meaning that the open face shield was not as beneficial as we initially thought.

Considering the open face shield did not provide enhanced communication over the sealed design, *we decided to move forward with only the sealed respirator* since this configuration is inherently safer (positive pressure) and has only small communication disadvantages.

Our design will be referred to as 'the device' or 'the respirator' for the remainder of the report.

5.3 Safety, Maintenance, and Repair Considerations

The safety of the user is our team's most important concern. We reviewed the safety of our design, creating the Design Hazard Checklist in Appendix N. This process investigates how the design will fail, considers how these failures might affect the customer, and focuses the team to work on the most critical potential issues. Many of the safety concerns include testing off-the-shelf products for reliability which will begin in mid-February.

Other safety precautions taken for the user are the following: the device is designed to be less than 5 lbs., sharp edges are to be rounded, no exposed wires, no excess hose length to avoid getting caught, and belt clips will be installed for easier transport of the device.

In order to mitigate damage to the device, it is enclosed and secured in a PLA 3D-printed housing and the wires are properly insulated and connected so they do not cause short circuiting in the device. Other protective measures include a well written manual on how to operate the device and to safely replace components for maintenance.

The components that will require maintenance or replacement depends heavily on the user's daily usage. The air filter will need to be changed the most often. The housing can remain closed, and the old filter will be unscrewed from the housing. The o-ring gasket around the filter outlet will need to be removed from the old filter and attached to the new one. The new filter must then be screwed onto the blower inlet of the housing. For the detailed assembly steps see section 6.3 below. The rest of the components should last significantly longer, but their part number, vendor location, and emails for customer support at each vendor will all be easily accessible in the manual the team writes up.

5.4 Cost Analysis

After sourcing components and compiling their prices, the total cost to construct a prototype of our design is approximately $140. The system's cost consists of six assemblies. These include: the blower assembly, which includes the blower, O-rings and screws ($14.47), the face mask ($15) the hose assembly which includes the hose and hose clamps ($17.92), the filter unit ($19.88) and miscellaneous items such as the 3-D printer filament and belt clips($24.88). The most expensive part is the battery with cables and wire crimp connectors ($47.56). However, these prices can be adjusted based on part selection. For example, a HEPA filter and 12V 6000mAh battery are used in our design; less stringent selection of these parts will decrease the cost. Again, to make our design more cost effective, we will provide an online platform for part selection and we will encourage others to suggest other parts to reduce cost.

Table 3. Cost of Components for Sealed Design.

Components	Sealed Design Price
Face Mask	$15
Hose	$17.92
Blower Assembly	$14.47
Battery	$47.56
Filter	$19.88
Additional Materials (Screws/Shrink Wrap/3D Filament)	$24.88
Total Price	$140 ($150.85 w/taxes)

6. Manufacturing

One of the main goals of our respirator was to make it easily manufactured by the customer. As a result, we designed the respirator to be made using mostly off-the-shelf parts, a few added 3D prints, and screws, hose clamps, and O-rings readily available at hardware stores.

6.1 Procurement

Our group believed that the most feasible place for all people to purchase materials was on Amazon.com. We attempted to search for all of our materials through here and while most of them where found, some had to be sourced elsewhere. A list of all the materials we purchased can found in the iBOM in Appendix G. In this document, you can see that most of our items were found through Amazon. The only main component that was not found on Amazon was our air filter, which can be found through Zoro, an eCommerce company that specializes on business supplies and tools. We reached out to several companies who also offered the filter we desired; Zoro's shipping time was the fastest compared to the other competitors. This filter has been specially fitted to our 3-D manufactured housing (threads are 44mm x 1/7"), so pay special attention to the threading if it is desired to purchase another cannister filter.

The housing for the filter, fan, and battery and the connector between the hose and snorkel mask were designed and 3D printed by our group. These components are posted online and can be found through thingiverse.com. Lastly, we purchased screws, O-rings, and hose clamps for our design through Ace Hardware. The item numbers can again be found in Appendix G.

6.2 Manufacturing

We have attempted to make our design as easy as possible for outside user's to manufacture the product themselves. As a result, we limited manufacturing s much as possible but are a couple of manufacturing operations relevant to our design: 3D printing and soldering.

6.2.1 3D Printing

There are three parts in our design that are 3D printed: the hose-mask connectors and the top half and the bottom half of the housing. All of these components were modeled in Solidworks and imported as stl files to Cura, a program called a 'slicer' which converts the model into printing instructions (G-code) for a given printer to print the parts.

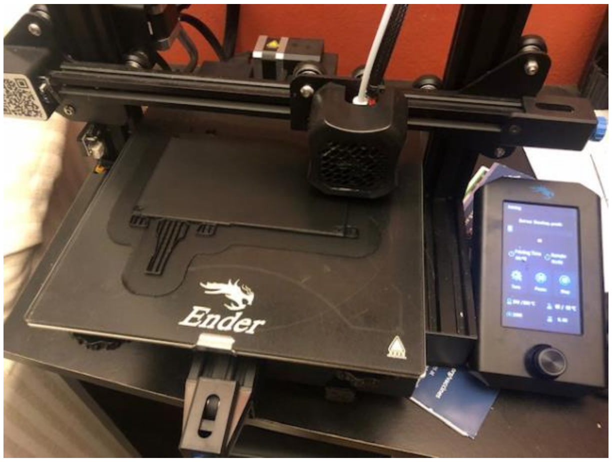


Figure 24. The bottom housing being printed on an Ender 3 V2.

Peter and Jomil own Ender 3 printers, and these printers were exclusively used for this project. Polylactic Acid (PLA) was used to print the hose-mask connector and the housing; however, Acrylonitrile Butadiene Styrene (ABS) would be acceptable as long as it is compatible with the printer in use and the profile implements a higher infill and wall thickness to promote part strength (ABS is weaker than PLA).

Because our design requires that the user manufacture these parts, we have posted the stl files for these parts online on thingiverse.com, which is mentioned in the paragraph above. As each 3D printer is different, we will leave it up to the user to choose their own slicer and profile. However, it is highly recommended to use support and to have a wall thickness of at least 2 – this will make the print stronger and more durable.

6.2.2 Soldering

To connect the battery to the blower requires XT60 connectors to be soldered to the battery and blower cables. The solders are protected by heat shrink.

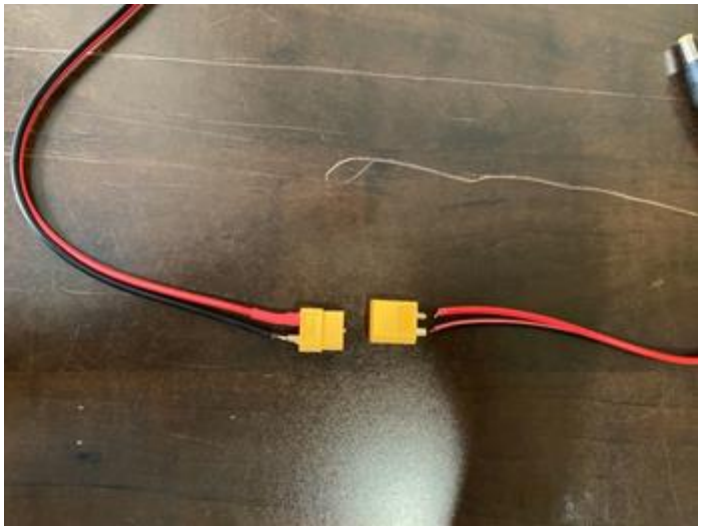


Figure 25. The left side is soldered, and the positive cable has a heat shrink protection. The right side is unsoldered.

First, flux is applied to the end of the wires. Then, small amount of solder is added to the wire to fill the wire and make it easier to solder to the XT60 connector. Be sure to put the heat shrink on the wire before soldering the XT60 connector on because the heat shrink will not fit over the connector and require 'de-soldering' to place it. Using a jig to secure the XT60 connector and the wire is important for safety and quality of solder. The XT60 connector was held by a mini vise and then the wire was placed inside of the connector. Then, solder is flowed so that it fills the area between the wire and connector. After waiting for the solder to cool, the heat shrink was applied to provide a protective seal around the solder.

This procedure was completed four times since the connectors link four wires together. It does not matter which side of the XT60 connector (female/male) is soldered to the battery or blower.

6.3 Assembly

As our design aims for the user to assemble the product, the steps needed to put together the device are listed below.

Step 1: Place the 2-½” O-ring down on the blower inlet, in the groove in the top housing piece.

Figure 26. Inside part of top half of housing.

Step 2: Place the blower in the housing and screw it to the housing using the three 10-24 x 3/8” screws. Be sure to hold the blower tight to the 3D printed housing so that there is a tight seal between blower and housing.

Figure 27. Top half of housing with screw positioning.

Step 3: Place the 1-5/8” O-ring around the threads on the filter.

Figure 28. Blower threaded side with O-ring.

Step 4: Attach the filter to the connector by screwing it into the top housing. When the filter is screwed into place, make sure that the O-ring is firmly seated between the filter and the housing. If the O-ring is not placed correctly, there is a risk that polluted air may get sucked in by the blower.

Figure 29. Top housing with filter attached.

Step 5: On the bottom housing, align the belt clip holes to the holes in the housing and insert the rivets through the hole and the belt clips. Note that each belt clip requires 2 rivets.

Figure 30. Bottom housing with belt clip and rivets, top on the left, bottom on the right.

Step 6: Use a hand punch, vise, or a hammer to secure rivets to the bottom housing.

Figure 31. Securing the rivets with a vise.

Step 7: Repeat steps 5 and 6 for remaining rivets to fully attach belt clips to the housing.

Figure 32. Bottom housing with both belt clips attached, top on left, bottom on right.

Next, we need to attach the battery to the blower to complete the housing assembly.

Step 8: Connect the cables of the blower into the male DC 2.1mm x 5.5 mm wire by clipping them together with the XT60 connectors.

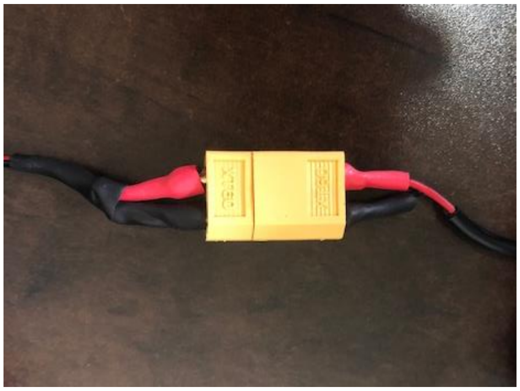


Figure 33. XT60 with wires connected.

Step 9: Put the filter, battery, and blower all inside our housing. Place the XT60 connectors in the cut out (as seen in the bottom housing seen on right) with the cabling through the small groove in the housing wall. Tighten housing together again using 10-24 x 1/2” screws where there are holes.

Figure 34. Blower and wiring inside housing.

The rest of the steps below are to put the rest of the face mask together. Make sure the first two subsystems are competed before continuing to Step 10.

Step 10: Attach the hose to the nozzle located on the housing. Tighten down with hose clamp, making sure not to overtighten.

Figure 35. Attachment of hose to housing.

Step 11: Place the 3D printed connector between the hose and the shield. Attach the hose to the connector and tighten down with hose clamp, making sure not to overtighten.

Figure 36. Attachment of snorkel mask to hose.

Step 12: Connect the DC battery cable into the outlet located on the battery.

Figure 37. On/Off button with DC cable plugged in.

Once you have completed all these steps, you will now have a fully functioning PAPR.

7. Design Verification

In this chapter, we will go through the five tests used to determine the validity and efficacy of our respirator device. Each chapter on testing will contain a description of the test, results, how it met or did not meet specification, assess presented data, establish a conclusion, and discuss challenges and lessons learned. For a more detailed explanation of the testing done, please refer to the DVPR in Appendix Q.

7.1. Particle Count Testing

The most important test conducted was our particle count testing. The purpose of this experiment was to determine if the filtered air that is being distributed into the mask meets our safety criterion of 99.90% filtration of viral particles. Our team was able to obtain a Model GT-321 Handheld Particle Counter and, by using this device, were able to measure the amount of 0.3-micron sized particles, the CDC recommended measurement size to exhibit the COVID-19 virus, within the enclosed area.

To perform this test, we needed the complete prototype with the addition of a mannequin head. Originally, we planned to measure the air that was inside the mask with the addition of a mannequin head to fully resemble a person using the device. First, the amount of 0.3-micron sized particles in the ambient air was measured. This number was needed to compare to the number of particles that were filtered inside the mask. Then, a small hole was made inside the face mannequin to be able to measure the particles inside of the respirator. A picture of this can be seen in the figure below.

Figure 38. Particle count testing setup.

Once the tube was able to measure the particles inside, we ran our respirator and took the measurements of particles inside every five minutes. Shortly after running this test, our efficiency was much lower than expected. As a result, we began to test the device in different configurations to see if there were any changes. A plot with these results can be seen in Fig. 40 below.

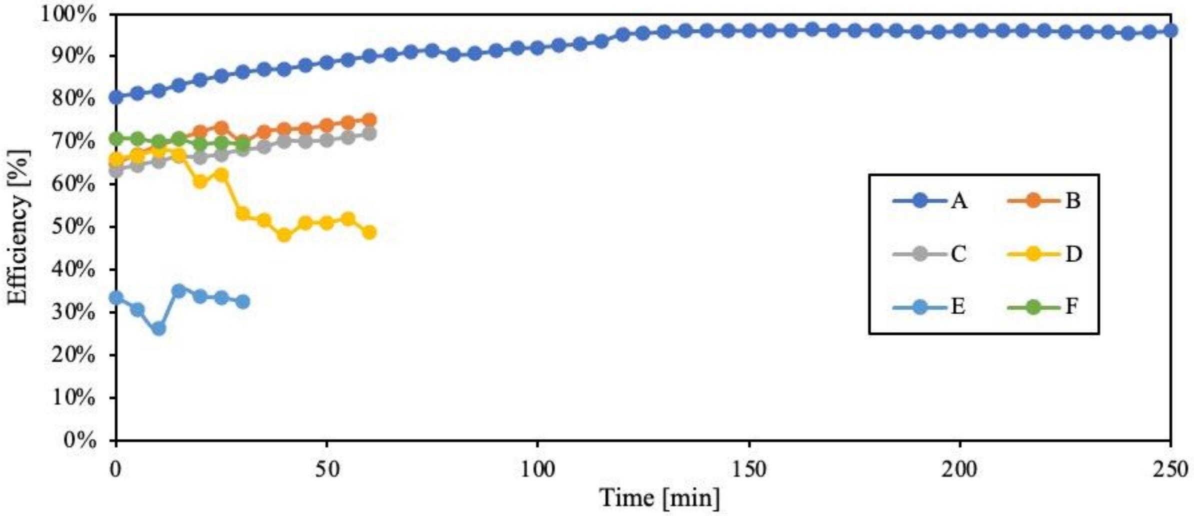


Figure 39. Particle count data plot.

We were expecting efficiencies of up to 99.93%, but recorded efficiencies ranging from 40-90%. In order to isolate where the problem was occurring, we began to test the efficiency our respirator component by component, starting with the filter alone. The efficiency of the filter alone measured as 99.97% effective, which was as advertised. The filter was connected to the housing and the efficiency was measured after it. We were able to confine the problem to the housing. The housing was redesigned by making it wider, allowing all the components to fit inside with some extra space. The housing was then tightly closed using screws and additional O-rings at the low-pressure areas. Also, every component was thoroughly cleaned, and dried and guarantee debris or dust were not causing the high particle count reading. The newly recorded efficiencies were 99.9%, which was closer to the range we expected. At last, the tube that carries the air to the user's face was attached and the air particles at the end of this tube were measured. The same efficiencies of 99.9% were recorded, which meant that our system was now bringing only filtered air to the user. Once this was resolved, more particle measurements of ambient air were taken and compared to the measurements that were coming out of the respirator’s tube. Some of these measurements may be seen below in table 4. Additionally, images of our filter, housing, and full respirator testing are below in figures 40 and 41.

Figure 40. Particle count testing alternative setups.

Figure 41. Final particle count test setup.

Table 4. Particle Count Testing Data.

	Hose		
Time [min]	**Ambient**	**Filtered**	**Efficiency**
0	394229	171	99.96%
3	392004	495	99.87%
6	385731	495	99.87%
9	379890	558	99.85%
12	384300	837	99.78%
15	439732	180	99.96%
18	409653	234	99.94%
21	422622	639	99.85%
24	419967	234	99.94%
27	420372	603	99.86%
30	419229	513	99.88%
33	419310	513	99.88%
36	428211	675	99.84%
39	420327	585	99.86%
42	421155	117	99.97%
45	391545	405	99.90%
48	421614	819	99.81%
51	419535	459	99.89%
54	405837	342	99.92%
57	404253	468	99.88%
60	413262	594	99.86%
63	421047	351	99.92%
66	438372	468	99.89%
69	412740	621	99.85%
72	411975	378	99.91%
75	422748	396	99.91%

On average, 99.91% of particles were being filtered, which met our acceptance value as seen on our DVPR, Appendix Q. This efficiency is higher than any other everyday use mask such as an N-95 or a surgical mask. Considering its low cost compared to other respirators on the market, we believe that the design of our mask is effective and an improvement from other regular masks.

This test was very difficult to plan for and perform. In the beginning, when we were reporting bad efficiencies, we were unsure of how to continue with testing, considering this was the most important feature of our respirator. If the device were not filtering out COVID-19 sized particles, the rest of the tests would not have much significance. Breaking down the device component by component was a very essential part in figuring out the problems with our mask. We learned to always look at a bigger scale problem part by part. If we continued testing without making any changes, we would have continued reporting efficiencies that were not close to our acceptance value. However, we were very pleased that we were ultimately able to test our device and meet its safety goals.

7.1.1. Statistical and Uncertainty Analysis

As the particle counting testing is the most important to our design, a statistical analysis on its data has been conducted. The histogram below in Figure 43 contains 90 data points compiled over four runs of the particle counting test procedure.

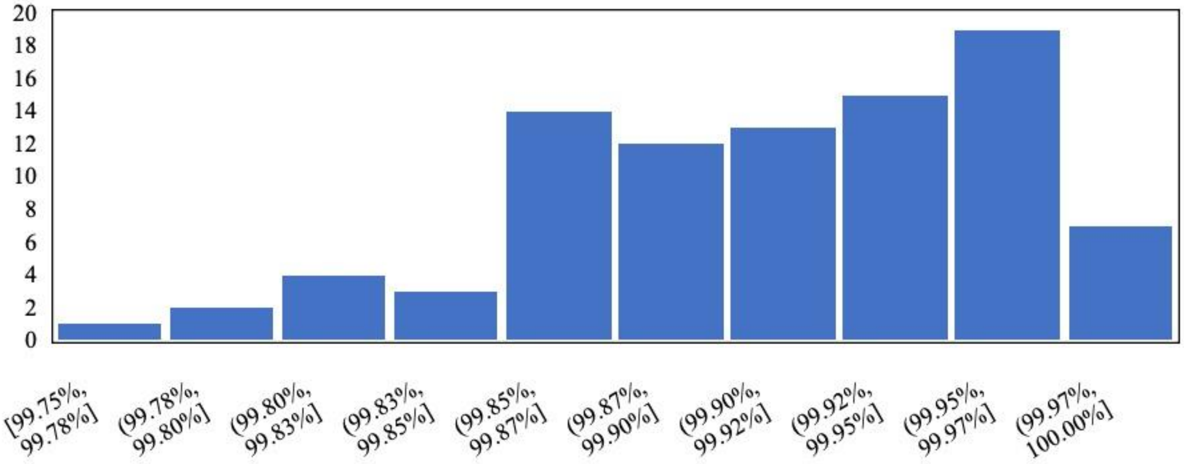


Figure 42. Histogram of particle counting data. There are 10 bins, with a width of 2.47%.

Since we have more than 50 samples, number of bins was calculated by taking the square root of the number of samples. The bin width was found by taking the difference between the minimum and maximum values of calculated efficiency and dividing by the number of bins.

Table 5. High Level Characteristics of the Dataset.

Sample Size	Average	Median	Mode	Standard Deviation
90	99.91%	99.92%	99.96%	0.05%

In this analysis, the data is model as being Gaussian. Note that despite the data not being the textbook definition of a Gaussian distribution (unimodal, symmetrical, and asymptotic to zero), modeling it as such is a very conservative approach. About 60% of the efficiency values are greater than the average of 99.91%, and the mode is one standard deviation above the mean. Modeling this data as Gaussian will eliminate the data's lean towards better efficiencies; therefore, being a conservative estimate of the filtration capabilities.

We have a sufficient sample size that we can model our data as a population. The objective of our data analysis is to establish confidence intervals; important intervals are below in Table 6. Please see Appendix K, Noteworthy Confidence Intervals Hand Calculations, for detailed work.

Table 6. Noteworthy Confidence Intervals.

Confidence that *Efficiency > 99.90%* (acceptance criteria)	55.96%
Efficiency > 65.8% (3-layer cotton mask)	~100%
Efficiency > 90.9% (2-layer denim mask)	~100%
Efficiency > 98.8% (vacuum cleaner bag inserted in mask)	~100%
Efficiency > 99.0% (surgical mask)	~100%
Efficiency > 99.3% (KN95 mask)	~100%
Efficiency > 99.97% (HEPA filter)	12.18%

Again, these values are conservative. Note that the efficiency levels obtained for the N95 and surgical masks were tested with an average particle size of 2.6 µm rather than 0.3 µm [20].

The conservative approach is apparent in the confidence interval for the acceptance criteria and the HEPA filter because these intervals are quite low considering the mode of the samples was 99.96%. Despite the confidence approach, the statistics prove very favorable for our design in comparison to the efficiencies of other masks. In fact, the statistics demonstrate that *our design has a 99.9% chance of having an efficiency greater than 99.75%!*

The efficiency of the respirator was calculated using the equation

$$Efficiency = \left(1 - \frac{filtered}{ambient}\right) \cdot 100\% \qquad \text{(Eq. 1)}$$

where *filtered* and *ambient* are the number of particles. The uncertainty in this calculation can be attributed to resolution and the manufacturer specified accuracy of the particle counter; the resolution uncertainty is ±5 particles and the specified accuracy is 10%.

The general method of uncertainty propagation was used to calculate the resulting uncertainty. Because the resolution uncertainty was much smaller than the specified accuracy, the resolution uncertainty was assumed to be zero; thus, for each filtered and ambient measurement, the uncertainty was calculated to be 10% of the reading. See Appendix L: Uncertainty Propagation Hand Calculations for detailed work.

Our sample size was 90; the average uncertainty across all measurements will be reported rather than the individual uncertainties for each measurement. *The average uncertainty was calculated to be ±0.013%*; a very small uncertainty considering the 10% instrument accuracy.

7.2. User Experience Survey

The objective of the user experience survey test was to obtain data on the overall comfort, visibility, communication ability, and aesthetic appeal of volunteer users while wearing our respirator. This test gave valuable insights on the non-technical performance of our device. Since the purpose of the respirator is protect the wearer without obstructing their daily tasks, these results are extremely important to verify that our respirator meets all our specifications. We conducted this test by having volunteers put on our completed verification prototype just as one would use in real application. The battery pack was clipped on to the user's lower-back, either on their pant waist band or a belt, if worn. The device was turned on and the mask was secured to the user's face. The team member and user stood 20 feet away from each other and began having a typical conversation at normal voice level. Each volunteer user was given the user experience survey, via Google form, to fill out as the test was run.

Each question was answered on a 0-10 scale, based on the user's personal experience and opinion with a final section to leave any extra comments. In addition, each team member recorded their ability to hear the user speaking on a scale of 0-10 which was recorded in a sperate file. A total of 9 trials were completed, each with a different volunteer user, taking an approximate time of 10 minutes to complete each trial. The average results from these trials are displayed in Table 7 below.

Table 7. User Experience Survey Questions and Results.

	Question on Survey:	Results (average rating):
Volunteer user questions:	1. How well could you hear the team members words from 20 feet away? (0-Not at all, 10-Very well)	9.2 (pass)
	2. How well did you feel the team member could hear you? (0-Not at all, 10-Very well)	5 (N/A)
	3. How well could you see your surroundings through the mask? (0-Not at all, 10-Very well)	6.8 (fail)
	4. How comfortable was the mask on your face and battery pack on your body? (0-very uncomfortable, 10-very comfortable)	7.6 (pass)
	5. Did you notice any fogging inside the mask? (0-none, 10- a lot)	0 (pass)
	6. How would you rate the aesthetic appeal of the device? (0-very unappealing, 10-very appealing)	6.2 (fail)
Team member question:	7. How well could you hear the user from 20 feet away, speaking at a normal volume? (0-not at all, 10-very well)	7.2 (pass)

Question number 2 on the survey was added as an additional check to compare the actual ability to hear the user's voice (from the team member) to the perceived ability to hear the user's voice (by the user). This question was not used in determining the acceptance of our device's communication, since the actual ability to hear the user's voice was noted by the team member and is most important for our specifications. However, the low ratings by the volunteer users do suggest that although they can be heard effectively, it does not feel that way when wearing the mask. This is likely due to the echo the user hears from the sound bouncing off the mask. Overall, our mask did meet our acceptance criteria of 70% approval rating for hearing the user's voice, but since the rating is still low, we may suggest adding a microphone and speaker system of the user's choice, so that the voice can really be amplified.

As for the other criteria in this test, the hearing ability of the user seemed to be virtually unobstructed since the mask does not cover the user's ears at all, and the background noise from the blower is very minimal. Additionally, our comfort and fogging rating both met our acceptance criteria. Not a single user noticed any fogging inside the mask while it was running during the entirety of use. Our two categories that did not meet their criteria were visibility and aesthetic appeal. Based on feedback from our user's we found that the curvature of the snorkel mask used, around the nose area, distorted the visibility when looking down through this area. However, visibility directly through the mask at eye level is good since that this section the mask is flat and thin. As for the aesthetic appeal, this criterion is highly subjective and difficult to truly quantify, although we were hoping for a higher overall response from outside volunteers. Both the visibility and aesthetic criteria can likely be improved by incorporating a different mask into the device which could be potentially sleeker and more "appealing" with a smoother, clear face surface. Based on our time constraints and budget. the snorkel mask we used was the best off-the-shelf mask we could find that could be easily integrated into our system and met our other specifications. In the future, a custom procured mask may be considered to improve visibility and aesthetic appeal rating.

As mentioned above, a major difficulty we faced regarding the user experience survey was confidence in the validity of our results since each of these categories are highly subjective and individual to each user. The 0-10 scale was the best measurement rating we could come up with to quantify our results. If possible, we would have liked to obtain a more objective rating for communication since this criterion is extremely important; however, with our resources the 0-10 rating was the most effective measurement procedure we could take. Additionally, due to the pandemic and current safety concerns we were limited in the demographic of users we were able to run the test on. Most volunteers consisted of roommates and friends of team members which were all young adults, none of which wore glasses or had facial hair which we believe would be an important consideration for our device. Ideally, we would add more trials from differing individuals to add diversity to our test group, which may influence some of our results.

7.3. Flowrate Verification Testing

Our flowrate verification test was primarily used to confirm our incoming filtered air quantity was sufficient to CDC guidelines for a sealed PAPR configuration. This acceptance criterion was 4.06 cfm, which we found on the CDC website, and compared to the average resting breathing rate of a person, is a conservative value. This should provide more than enough air to the user. After discussing with Cal Poly professor, Dr. Hans Mayer, we discovered the difficulties we would face with this test. Firstly, it is critical to measure the flowrate with the entire system connected, including the face mask secured to an object to simulate a human head. This is because each component adds additional fluid losses which may decrease the flowrate. Therefore, it was necessary to find an in-line flowmeter. This meant that the measurement device could be integrated into the running system. The second important consideration for the measurement device was that it provided minimal additional losses to the system. Any tool we decided to use would add some restriction to the flow, therefore decreasing the measurement, but we aimed to minimize this effect. With these considerations in mind, our measurement tool of choice was a hot wire anemometer, which we obtained from our project advisor, Dr. Kean.

To conduct this test, we 3D-printed a hollow, cylindrical test duct section with a small hole in the side that fit the hot-wire anemometer test probe. This duct was attached at the end of the hose and connected to the inlet of the mask, replacing the connector piece that usually connects these components in the assembled device. Everything else about the device was kept the same, and the mask was secured to our mannequin head. The battery pack was placed below the mask and mannequin head to best simulate the location of both components on the actual body. Finally, the hot wire anemometer probe was placed inside the test duct hole and the device was turned on. The test procedure setup can be seen below in Figure 44.

Figure 43. Flowrate verification test.

Velocity readings in ft/s were recorded every two minutes for a total of one hour. These readings were multiped by the cross-sectional area of the duct in ft^2 to obtain the flowrate in cfm. The data from this test is shown below.

We found over the one-hour time period our average flowrate to be 11.99 cfm. The lowest flowrate we recorded was 11.52 cfm and the highest was 12.42 cfm. These results meet and exceed our acceptance criteria for the necessary flowrate, by almost 300%. This was somewhat as we excepted, just from qualitative observation of the amount of air flow into the mask. We are satisfied with these results as there is no downside we have discovered to this high flowrate, since it successfully removes any condensation that may cause fogging and is a very comfortable amount of air based on feedback from users. Seeing that we have found our flowrate is high enough to be safe for the user, any surplus from that point is used to maintain comfort.

Table 8. Flow Rate Verification Test Results.

Time [min]	Velocity [ft/min]	Flow rate [cfm]	Flow rate [L/min]
0	1380	12.33	349.20
2	1380	12.33	349.20
4	1390	12.42	351.73
6	1390	12.42	351.73
8	1360	12.15	344.14
10	1370	12.24	346.67
12	1360	12.15	344.14
14	1310	11.71	331.48
16	1340	11.97	339.08
18	1340	11.97	339.08
20	1320	11.80	334.01
22	1350	12.06	341.61
24	1340	11.97	339.08
26	1370	12.24	346.67
28	1360	12.15	344.14
30	1350	12.06	341.61
32	1350	12.06	341.61
34	1330	11.88	336.55
36	1350	12.06	341.61
38	1340	11.97	339.08
40	1350	12.06	341.61
42	1340	11.97	339.08
44	1330	11.88	336.55
46	1340	11.97	339.08
48	1340	11.97	339.08
50	1340	11.97	339.08
52	1310	11.71	331.48
54	1300	11.62	328.95
56	1300	11.62	328.95
58	1290	11.53	326.42
60	1290	11.53	326.42

7.4. Battery Life Testing

In consideration of the main users of this respirator being Cal Poly professors, we had to design our device so that could last up to 6 hours, the time equivalent of two lab periods. The purpose of this test was to find the reliability of the battery over this time period. To perform this test, we needed the whole system running to account for the resistances that the battery would have to will have to overcome to power the blower through the hose and mask. Additionally, we needed a multimeter and a timer to make sure the voltage of the battery at a sufficient level over the six hours necessary. For this experiment, we only had one potential hazard. There was the possibility of the battery overheating since the battery for had not run for six hours prior to this experiment. To manage this, the battery was monitored throughout all six hours to make sure it did not overheat.

Table 9. Battery Life Testing Data.

Minutes	**Voltage**
0	12.29
10	12.21
20	12.14
30	12.09
40	12.04
50	12.02
60	12.00
70	11.97
80	11.93
90	11.89
100	11.84
110	11.80
120	11.77
130	11.73
140	11.67
150	11.62
160	11.57
170	11.53
180	11.50
190	11.46
200	11.42
210	11.40
220	11.42
230	11.38
240	11.35
250	11.32
260	11.29
270	11.25
280	11.22
290	11.19
300	11.17
310	11.14
320	11.11
330	11.08
340	11.06
350	11.04
360	11.01

To perform this experiment, we began by putting the mannequin head inside the mask respirator. This was important because all losses that would be present in real application should be present while testing. Before beginning, we ensured the battery was fully charged. The system was then turned on. Voltage measurements were taken from the battery system every 10 minutes for six hours.

After performing the experiment, we found that our battery exceeded our expectations. After taking voltage measurements for 6 hours, the battery life only went down 20%. This meant that it could be used for much more than six hours, which was our acceptance criteria described in the DVPR. Furthermore, the voltage stayed very constant, only going down from 12.29 V to 11.01 V over a span of 6 hours. This can be seen in the table above.

From this data, we were able to conclude that this respirator will be able to keep professors safe for the length of two Cal Poly labs. Even though the voltage of the battery went down 1V, the flow rate from the blower was still in excess to what is recommended by the CDC and our DVPR acceptance criteria.

During this experiment, there were not any significant challenges encountered. The battery did not overheat and the wiring of the battery to the blower was not disconnected. The experiment was very simple, and the data followed a linear pattern, which showed it was taken correctly. The main concern with our battery is how long it will take to deteriorate. We know that over time, the battery will get weaker. However, considering our time limit this quarter, we would need more time to see the behavior of the battery over a long period of time.

7.5. General Use Testing

This general use testing consisted of two smaller tests: timing volunteers to see how quickly they were able to put on and take off the respirator and how long it took for them to fully sanitize the mask using a disinfecting wipe. These tests were conducted to ensure that the device was designed with customer needs in mind, i.e., does not take much time to put on, take off, or maintain.

The application and removal time testing was performed by a team member and volunteer user. The team member would begin the timer as the volunteer user began putting on the device. Once the device was properly secured onto the user, the team member would record the time taken. The same was done for the removal of the device. The results from this testing showed that the mask took an average of 78.7 seconds to put on and 17.5 seconds to take off. The application time did meet the acceptance time of 60 seconds. The removal time did not meet the acceptance time of 60 seconds. The table below displays the data taken during testing.

Table 10. Application and Removal Time Testing Data.

Run #	Application Time [s]	Removal Time [s]
1	96	4
2	167	60
3	43	10
4	35	9
5	62	12
6	69	10

Observing this data, we found that the longer application and removal times resulted from testers placing the battery pack on a belt at the small of their backs. Although this took longer, testers felt that this placement allowed for a wider range of motion and made the weight of the device less noticeable. We also found that those who were more familiar with the device were able to put it on and take it off much faster than those who were handling the device for the first time. This demonstrates that the more the user puts on and takes off the device the faster they will become at it, decreasing the overall application and removal time. From the collected data, we feel that the belt clips used to attach the device to the user are sufficient.

Some challenges we faced while conducting this testing were not having a bigger sample size and not having the proper tooling to install the rivets on belt clips. Due to the pandemic and time constraints, we were unable to test on a larger population of users from fear of spreading the virus. We would have liked to test on users of different ages, face and body shapes, facial hair lengths, and glasses types. Due to inability to acquire proper tooling, the rivets we installed were not completely flush to the backing of the battery pack. This caused the testers to have a bit of trouble attaching and removing the belt clips to and from their pants' waistbands or belts, increasing application and removal time. We learned that we should have fixed this issue before starting testing because it may have affected our data.

The sanitization testing was performed by a team member and volunteer user. The team member would begin the timer as the volunteer user began wiping down the device with a commercially available disinfecting wipe. Once the device was properly sanitized, the team member would record the time taken to perform this task. The results from this testing revealed that, on average, the respirator took 112.8 seconds to be completely wiped down using commercially available disinfecting wipes. This met the acceptance time of 120 seconds. The table below displays the data taken during testing.

Table 11. Sanitization Time Testing Data.

Run #	Sanitization Time [s]
1	152
2	117
3	145
4	115
5	67
6	81

Observing this data, we concluded that testers had a wide range of times due to what each person thought was sufficient to sanitize the device. Some only wiped down the device once while others wiped down the device two to three times to sanitize the device. No matter how long the testers took to wipe down the device, it seemed that our acceptance time of 120 seconds was close enough to the averaged times that testers did not mind spending sanitizing the device after use.

A challenge that occurred during testing was that the disinfecting wipes made the snorkel mask splotchy when it dried. This was easily fixed by drying up the residual liquid left by the wipe using a paper towel, but this also creates more waste than we would like. We learned that we should have tested different types of commercially available sanitization liquids and wipes on the snorkel mask before testing occurred.

7.6. Supplemental Testing

In addition to the tests we conducted, there are several additional tests that would be beneficial in further verifying our design. These supplemental tests include leak testing and quantitative communication testing.

The team did not prioritize a leak test because of the positive pressure environment; however, it still would be an informative test because it would experimentally verify that the device's positive pressure is warding off ambient air from intrusion.

Evaluating oral communication was a difficult task for our team; specifically finding ways to quantify the clarity and volume of the user's voice while wearing the respirator. Our user experience survey asked participants to rate how well they thought they could be heard from 20 feet. While this data is very helpful, attaching numerical data to measure communication levels would be incredibly useful.

The idea of measuring the noise level of a person speaking while wearing the device was discussed, but ultimately scrapped because the blower's noise levels would impact the volume of the user's voice. The team had taken some preliminary data with a decibel meter, and recorded that at 20 feet away, the blower was 48 dB; a person speaking with the device was 52 dB. This data should be taken with a grain of salt because the decibel readings were taken as an average over 15 seconds, and the readings could have been influenced by the outside noise. Additionally, this test does not differentiate the blower noise from the user's voice volume; therefore the 52 dB measurement is not a direct measurement of the user's voice level while operating the blower. And finally, the decibel testing does not capture the clarity of the user's voice.

Dr. Kean suggested to evaluate the clarity of the user's voice, it was discussed asking the user to read a short script and have a panel of people try and write down what the user said and grade the panel on their translation. This idea was also not used because an audio recording may not be an accurate reflection of real-life sound since background noises may not be picked up as well by an audio recording and can skew our data.

To solve the oral communication problems, the team had previously broached including a microphone and speaker into the design. The microphone and speaker's integration with the rest of the system would be evaluated in the user experience survey, but the problem of developing tests which provided numerical, non-arbitrary data would still exist.

Leak testing and improvements on oral communication testing are two areas in which are design could be better tested.

7.7. Conclusive Remarks on Testing Results

After analyzing the data from the five tests performed and comparing the results to our acceptance criterion, we believe that our design meets most of our design criteria. This can be seen in our in the table below and in our DVPR, Appendix Q. The device passed eight out of twelve tests that were conducted and two of the tests that failed, namely the application time testing and the particle count testing, failed marginally close to the acceptance criterion. Considering the time constraint and the ten times price decrease from a commercially available PAPR, the respirator was completed to the best of our ability.

Table 12. Summarized DVPR with Pass/Fail Column.

Spec #	Parameter Description	Test	Acceptance Criteria	Pass/Fail
1	Comfort Study	User experience survey	85% approval	Pass
2	Rechargeable battery	Battery Life Characterization	6 hours	Pass
3	Flowrate (for positive pressure)	Flowrate Verification	115 L/min (4.06 cfm)	Pass
4	Can clearly hear user	User experience survey	20 feet away, 70% approval	Pass
5	User can see clearly	User experience survey	85% approval	Fail
6	User can hear clearly	User experience survey	20 feet away	Pass
7	Anti-fogging	User experience survey	Less than 2 (0-10 scale)	Pass
8	Cleaning time (daily)	General Use	2 min.	Pass
9	Application/removal time	General Use	60 sec.	Fail/Pass
10	Size	N/A	6 in. off body	Pass
11	Weight	N/A	5 lbs.	Pass
12	PPM	Particle Counter Test	99.90%	Pass
13	Cost	N/A	$200	Pass
14	Appearance survey	User experience survey	70% approval	Fail

8. Project Management

Through the past three quarters, we followed a Gantt chart (Appendix S) to plan and meet our goals for this project. We continuously kept updating it to reflect quarterly goals that came up as we looked to finish the project. This was very helpful to us since we were able to stay on track for the project throughout the whole year. If we were to use this method over again, the only change we would make is to move due dates earlier than when they are due to have extra time to proofread and modify our results.

Our overall design process was built on ideation and iteration. After we created a structural prototype, we made a Design Verification Plan (DVP) to track and analyze the results of testing. With the DVP, we set a timeframe for when the tests would be done and marked whether or not they passed our original specifications for each test. This worked effectively as it gave us a visual representation of how we were progressing through our testing. These two documents helped the team finish the project on time.

9. Conclusion

Through this project, our team was able to create a low cost PAPR that can keep professors and others safe from COVID-19 and other viruses. It is very accessible, as Cal Poly professors all have access to 3-D printers on campus to print the connector and housing, and the majority of our other parts can be purchased on amazon. It met most of our criteria, passing all of the safety and critical main function tests, meaning we consider this project an overall success. While not a requirement, we were not able to add the outflow filter to our mask. In future prototypes of this respirator, we would look further into adding this component as it would protect others around and not just the person wearing it. Also, as stated in our testing, we would look into a different face mask to improve the aesthetics and visibility of our respirator, so that it could meet the remaining criteria. If we were to do this project all over again, we would focus more on testing sooner and reaching out to more professors for input. All of our testing was done in a limited amount of time, which meant we could not modify much after our results came back. Then, having the input of professors on the device would help in the experience survey results. Overall, this was a fun project to work on and we hope further prototyped can be made in the future.

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Appendices

[A] QFD House of Quality
[B] Function Decomposition Brainstorming Table
[C] Initial Concept Prototypes
[D] Pugh Matrices
[E] Morphological Matrix
[F] Weighted Design Matrix
[G] Indented Bill of Materials
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[K] Noteworthy Confidence Intervals Hand Calculations
[L] Uncertainty Propagation Hand Calculations
[M] Failure Modes & Effects Analysis
[N] Design Hazard Checklist
[O] Risk Assessment
[P] User Manual
[Q] Design Verification Plan & Report
[R] Test Procedures
[S] Gantt Charts

Appendix [A]: QFD House of Quality

Correlations	
Positive	+
Negative	−
No Correlation	

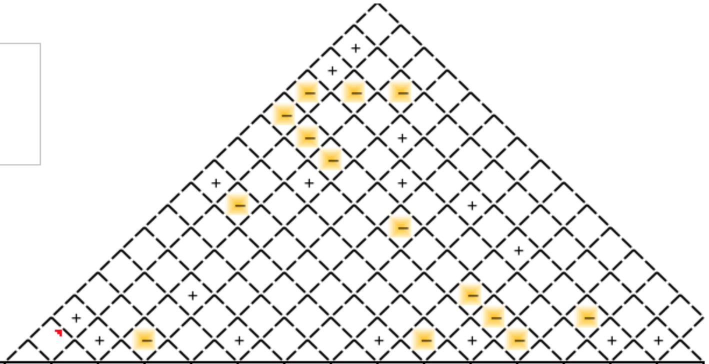
Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

QFD House of Quality

Project: F62 Face Shielders

Revision Date: October 6, 2020



Row #	Weight Chart	Relative Weight	Cal Poly Professors	Manufacturer	Essential Workers	Students	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) \ HOW: Engineering Specifications (Tests)	Comfort Study	Rechargeable battery	Flowrate (positive pressure)	Clearly hear user	Can see user's face	mask doesn't fog-up	Cleaning time	Application/removal time	Weight	Durability	PPM	Cost	Appearance Survey	Size	User can hear	N95 Mask	PAPR (full hood)	Non-powered respirator	PAPR Full face	Row #
	WHO: Customers							Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	NOW: Curr. Products				
								Direction of Improvement	▲	▲	◇	▲	▲	▼	▼	▼	▼	▲	◇	▼	▲	▼	▲					
1		15%	9	8	10	8	9	Comfort	●		●			●		▽	●					●	○	4	4	2	4	1
2		14%	9	2	7	7	9	Easy communication			▽	●	●	○									●	3	2	1	4	2
3		11%	7	4	6	7	9	Good visibility			○		○	●										5	4	3	4	3
4		6%	6	6	8	9	9	Easy transport/storage		○						○	●	▽				●		5	2	3	3	4
5		16%	10	10	10	10	9	Effective filtration (safety)		○	●				▽				●					3	5	3	4	5
6		6%	5	7	9	7	9	Reusable		●					●			●						1	4	4	4	6
7		6%	4	6	6	4	9	Easy to operate		▽				▽	●	●	▽					▽		5	4	4	4	7
8		2%	2	5	6	4	9	Aesthetically pleasing	▽				▽								●	○		2	2	2	2	8
9		14%	8	10	9	10	9	Affordable	▽	○					▽			▽		●				5	1	3	1	9
10		10%	5	9	5	5	3	Accessiblility		▽										○				4	3	4	3	10

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	HOW MUCH: Target Values	85% Approval rate	6 hour battery life	115 L/min	20 feet away	80% exposed	Yes/No	2 minutes (daily)	45 seconds	5 pounds	2 years	99.50%	$200	70% approval rate	3 inches off body	20 feet away
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
	Technical Importance Rating	151	178	326	126	161	282	138	87	195	74	144	156	18	201	171
	Relative Weight	6%	7%	14%	5%	7%	12%	6%	4%	8%	3%	6%	6%	1%	8%	7%
Curr. Products	N95 Mask	4			3	1	5		5	5	0	3	5	2	5	5
	PAPR (full hood)	4	5	5	2	4	5	2	3	2	3	5	1	3	2	3
	Non-powered respirator	2			1	1	3	3	5	5	4	3	4	2	5	5
	PAPR Full face	4	5	5	2	5	5	3	4	4	4	4	1	2	3	4
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

Appendix [B]: Function Decomposition Brainstorming Table

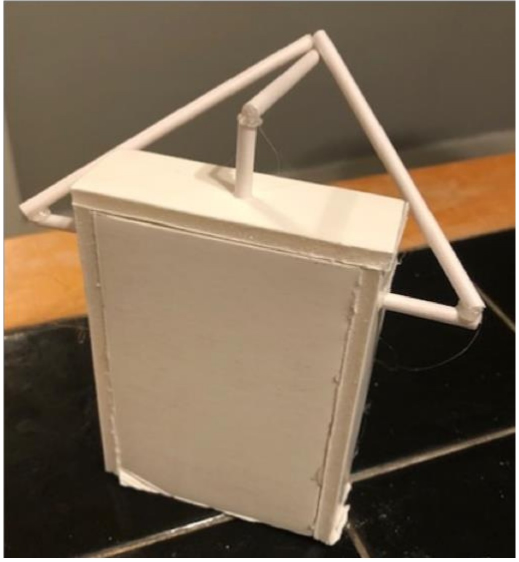
Subfunctions	Ideas
Provides Comfort	• Materials (covering) o Polyester $ o Nylon $ o Lycra $$ • Materials (padding) o Foam o Gasket o Plastic ring of air • Design Goals o Making mask with breathable material for straps and features o Size variation? (Small, medium large?) o Make adjustable to fit everyone properly
Make Accessible	• Using commercially available parts (i.e. from Home Depot, Amazon) • 3D printable parts file(s) • Non-technical instructions on how/where to buy parts and how to put it together • Limit movable parts/ limit number of parts/ SIMPLIFY • Starter kit • Video on how to use, construct, and operate
Provides Clean Air to and from User	• Non-powered air filter for outlet air near chin area • Have filters on vents on the side of the face • Use cutup N95 masks for filters • Tube and fan/motor for inlet air • Type of motor/blower - fan, suction pressure difference • Multiple hoses into mask
Allows Clear Communication	• Mask doesn't cover ears • Clear shield • Speaker inside mask • Microphone inside mask • Anti-fog o Or flowrate decreases fog o Dehumidifying component (silica beads) o Material or coating • Anti-glare o Material o Coating • UV light protection o Protective coating o Visor attachment

	o Photochromic lenses face shield (coating) (it's already UV protective) • Have fan/motor further away from face due to hearing inhibition o Make sure flowrate doesn't affect ability to hear • Mask can have electrical components – i.e. maybe have an audio jack or USB port, Bluetooth??? o Enhance surrounding sound to user and enhance user's voice to others
Interface with Head/Body	• Buckle system for straps • Knob to tighten? • Elastic straps o Vertical vs horizontal • Plastic instead of glass shield to make it collapsible o Clear, flexible plastic for shield • Shield will only cover user's face • System for the battery o Backpack o Sling o Belt o Chest pack o Arm band o Similar to drum holster • Attach battery near back or top of head • Collapsible hose • Possibility of mask folding itself into it's own carrier • Battery can fit inside face shield for easy, compact transportation • Ability to flip mask up to drink water or something o Automated? o Half mask? o Only clear part? o Retractable visor o Flip up visor • Magnetic battery pack (easy attachment, transportation, charging?) • Hose from blower to mask is flexible, maybe changes sizes. The point is that it can be put out of the way and doesn't become tangled in user's motion • Easy buckling system o Slap wrist bracelet

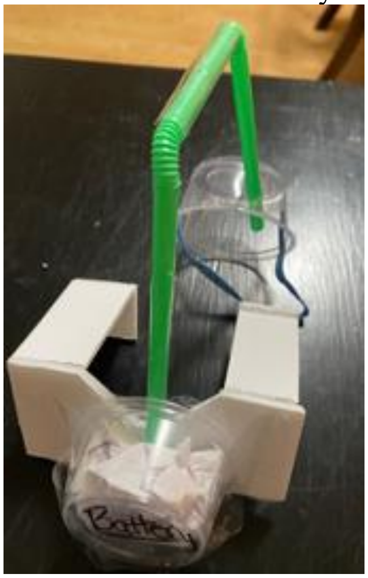
Appendix [C]: Initial Concept Prototypes

Detachable, size varying face cushions

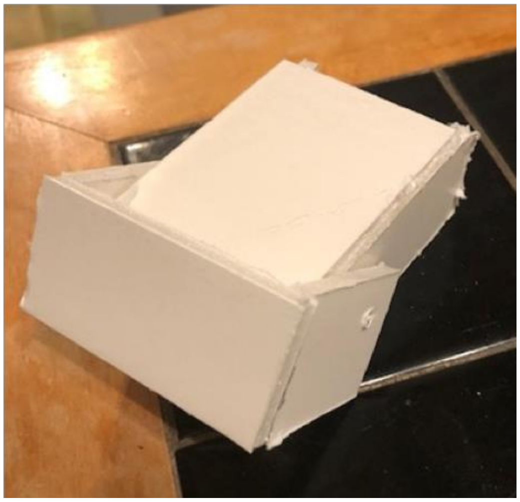
Multiple air inlet hoses on shield



Over the shoulder holster system



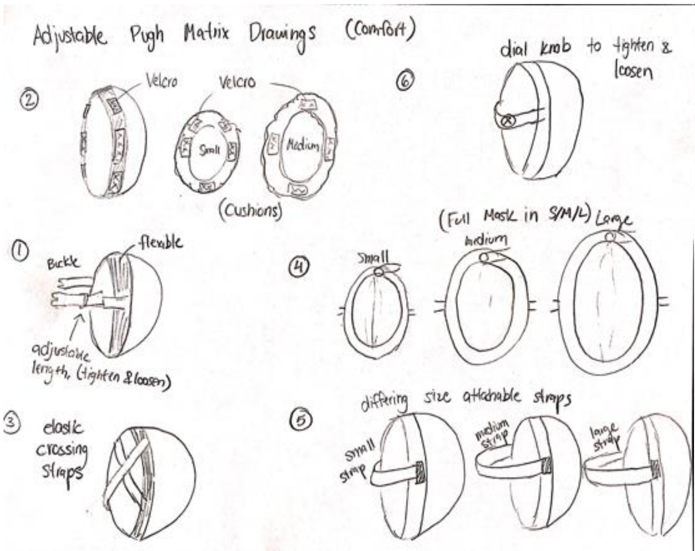
Retractable Visor

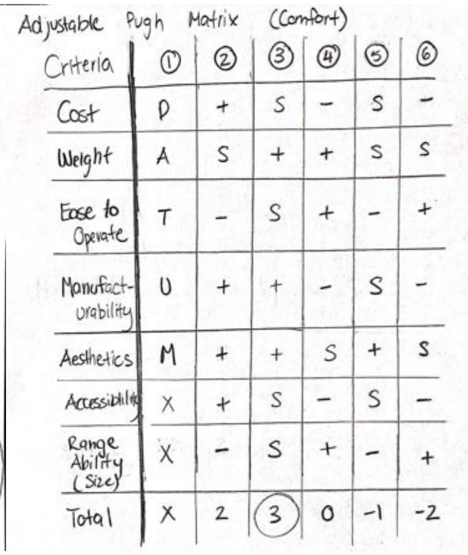


Elastic Head Strap

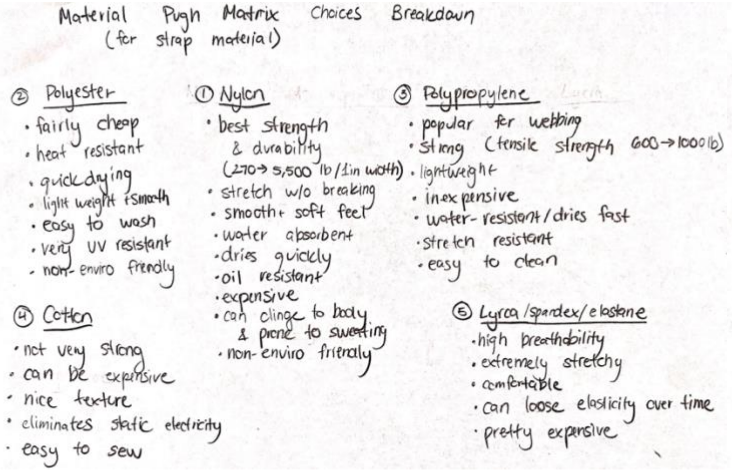
Appendix [D]: Pugh Matrices

Provides Comfort Pugh Matrices:




Adjustable Pugh Matrix (Comfort)

Criteria	①	②	③	④	⑤	⑥
Cost	D	+	S	–	S	–
Weight	A	S	+	+	S	S
Ease to Operate	T	–	S	+	–	+
Manufact-urability	U	+	+	–	S	–
Aesthetics	M	+	+	S	+	S
Accessibility	X	+	S	–	S	–
Range Ability (Size)	X	–	S	+	–	+
Total	X	2	3	0	-1	-2


Material Pugh Matrix Choices Breakdown
(for strap material)

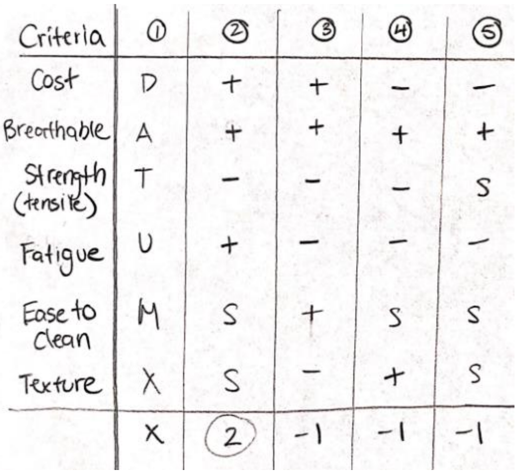
② Polyester
- fairly cheap
- heat resistant
- quick drying
- light weight + smooth
- easy to wash
- very UV resistant
- non-enviro friendly

④ Cotton
- not very strong
- can be expensive
- nice texture
- eliminates static electricity
- easy to sew

① Nylon
- best strength & durability (270→ 5,500 lb/1in width)
- stretch w/o breaking
- smooth + soft feel
- water absorbent
- dries quickly
- oil resistant
- expensive
- can clinge to body & prone to sweating
- non-enviro friendly

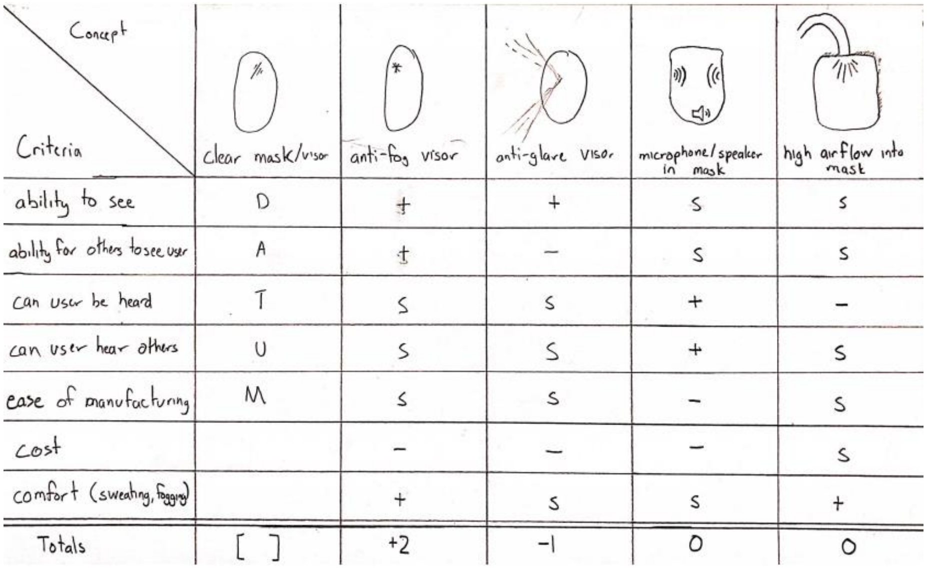
③ Polypropylene
- popular for webbing
- strong (tensile strength 600→1000 lb)
- lightweight
- inexpensive
- water-resistant/dries fast
- stretch resistant
- easy to clean

⑤ Lyrca/spandex/elastane
- high breathability
- extremely stretchy
- comfortable
- can loose elasticity over time
- pretty expensive



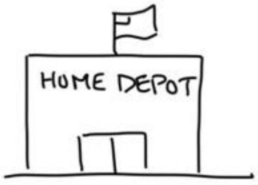
Criteria	①	②	③	④	⑤
Cost	D	+	+	–	–
Breathable	A	+	+	+	+
Strength (tensile)	T	–	–	–	S
Fatigue	U	+	–	–	–
Ease to Clean	M	S	+	S	S
Texture	X	S	–	+	S
	X	2	-1	-1	-1

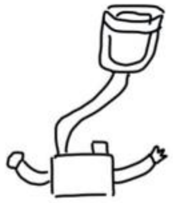
Clear Communication Pugh Matrix:



Criteria \ Concept	clear mask/visor	anti-fog visor	anti-glare visor	microphone/speaker in mask	high airflow into mask
ability to see	D	+	+	S	S
ability for others to see user	A	+	–	S	S
can user be heard	T	S	S	+	–
can user hear others	U	S	S	+	S
ease of manufacturing	M	S	S	–	S
cost		–	–	–	S
comfort (sweating, fogging)		+	S	S	+
Totals	[ ]	+2	-1	0	0

Accessibility Pugh Matrix:





Customer Requirements	Kit and video on how to put together and use	Use commercially available parts	3D printable part file(s)	Non-tech instructions on how/where to buy parts	Limit movable parts	Starter Kit
Easy to operate	Datum	-	-	-	+	+
Affordable	Datum	S	+	-	S	S
Accessibility	Datum	S	+	+	-	S
	Sum of -	1	1	2	1	0
	Sum of +	0	2	1	1	1
	Sum of S	2	0	0	1	2

Clean Air to User Pugh Matrix:


Optrel e3000x


Non-powered air filter near chin area


Tube & fan for inlet air


Multiple hoses into mask

Customer Requirements	Optrel e3000x	Non-powered air filter near chin area	Tube & fan for inlet air	Multiple hoses into mask
Effective filtration (safety)	Datum	-	S	S
Reusable	Datum	S	S	S
Accessibility	Datum	S	S	S
Cost	Datum	-	S	+
Ease of Transport	Datum	+	S	-
Comfort	Datum	-	S	+
	Sum of -	3	0	1
	Sum of +	1	0	2
	Sum of S	2	6	3

Clean Air From User Pugh Matrix:


N95 mask


Filters on vents on side of face

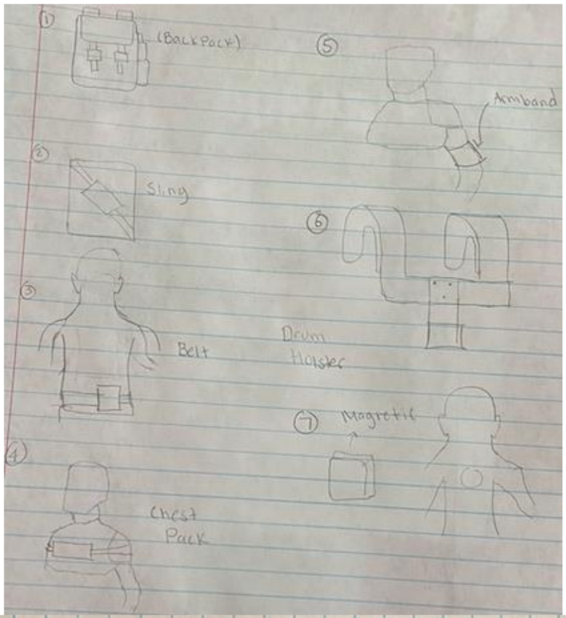

Non-powered air filter near chin area

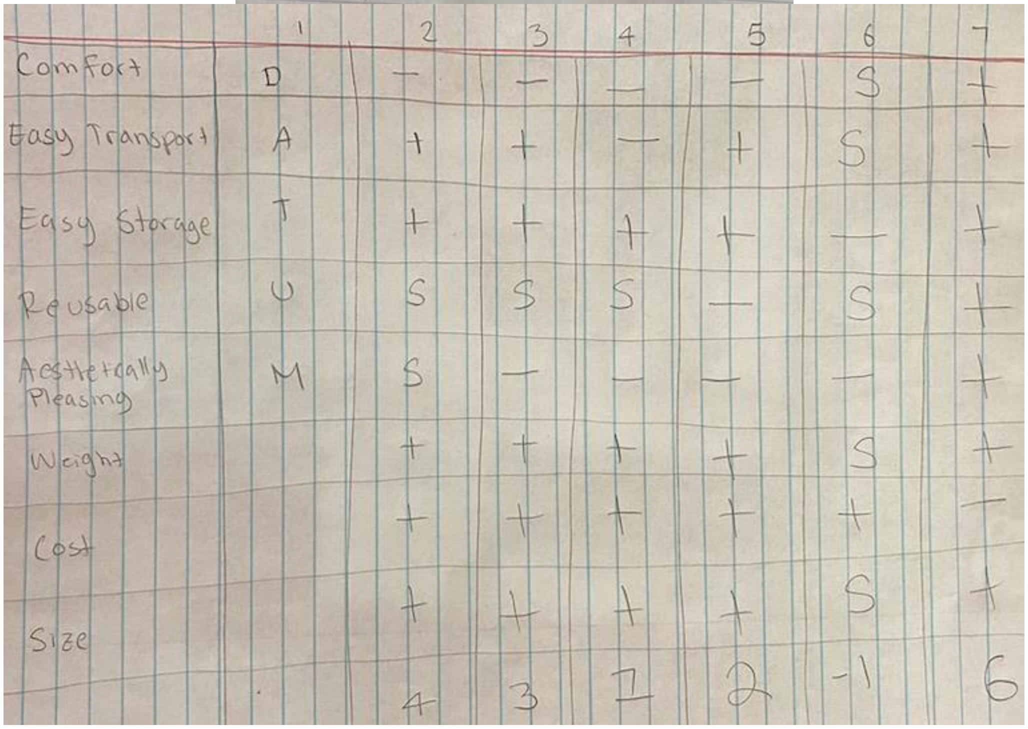

1 inlet tube and
1 outlet tube


UV light sanitation

Customer Requirements	N95 mask	Filters on vents on the side of the face	Filter tubes near chin area	1 inlet tube and 1 outlet tube	UV light sanitation
Effective filtration (safety)	Datum	+	S	+	+
Reusable	Datum	S	+	+	+
Accessibility	Datum	S	-	+	-
Cost	Datum	S	-	-	-
Ease of Transport	Datum	-	-	-	-
Comfort	Datum	+	-	-	+
	Sum of -	1	4	3	3
	Sum of +	2	1	3	3
	Sum of S	3	1	0	0

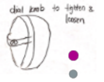
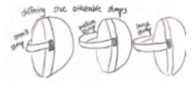
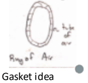
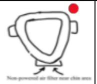
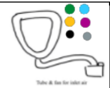
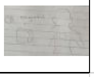
Interface with Battery Pugh Matrix:





	1	2	3	4	5	6	7
Comfort	D	—	—	—	—	S	+
Easy Transport	A	+	+	—	+	S	+
Easy Storage	T	+	+	+	+	—	+
Reusable	U	S	S	S	—	S	+
Aesthetically Pleasing	M	S	—	—	—	—	+
Weight		+	+	+	+	S	+
Cost		+	+	+	+	+	—
Size		+	+	+	+	S	+
		4	3	1	2	-1	6

Appendix [E]: Morphological Matrix

Function	Importance	Potential Solutions														
		Material					Strap/Buckle				How Mask Sits on User's Face					
Comfort	9	Nylon	🟢 Polyester 💚 🔴	🟣 ⚫ Polypropylene 🟡	🔵 ⚪ Cotton	🟢 Lycra / Spandex / Elastane	 elastic crossing straps 🟢 🟣 🔵 ⚫ 🟡	🔴  Buckle flexible adjustable length (tighten & loosen) 💚	 dial knob to tighten & loosen 🟣 ⚪	 differing size attachable straps small strap medium strap large strap	🟣  Velcro Velcro Small Medium (Cushions) 🟢 💚 ⚫ ⚪	🟣 🟡 ⚫  tube of air Ring of Air ⚪ Gasket idea	🔴 🔵  foam strategically placed foam	 foam Insulating Ring	 adheres like swim goggles aking plastic	🟣 Hybrid, velcro along mask which different sized gaskets fit to
		Visor Modifications					Type									
Clear Communication	8	⚪ 💚 🔴 🟢 🔵 🟣 🟡 ⚫  clear mask/visor	💚 🟢 ⚪ 🔵 🟣 🟡 ⚫  anti-fog visor	💚 🟢 🔵 ⚪ 🟣 🟡 ⚫  anti-glare visor	🟡 🟣 ⚫ ⚪  microphone/speaker in mask	💚  high airflow into mask	🟢 🟣 🟡 ⚫ ⚪ Fully-sealed	covering ears	🔴 🟢 🔵 🟣 🟡 💚 ⚫ ⚪ not covering ears							
		Clean air FROM user				Clean air TO user			Method of Removing Covid							
Clean Air to and from User	10	 UV light sanitation	🔴 ⚫ 🟢  🔵 💚 Filters on vents on side of face 🟣 ⚪	 Non-powered air filter near chin area 🟡	 1 inlet tube and 1 outlet tube	🔴  Non-powered air filter near chin area	🟢 🔵 🟡 🟣 ⚫ ⚪  Tube & fan for inlet air	💚  Multiple hoses into mask	HEPA	N95	🔴 Cloth	UV radiation				
		Battery Pack Attachment System														
Interface with Body	7	⚫ 	🔵 🟣 	🔵 💚 	 🟡	🟢 ⚪ 										

Legend
🔴 Cheapest
🟢 Highest Scoring Pugh Matrices
🔵 Feasibility
🟣 Customer Needs?
🟡 Peter's Favorite
⚪ Becky's Favorite
💚 Julia's Favorite
⚫ Jomil's Favorite

Appendix [F]: Weighted Decision Matrix

Criteria	Weight	Cheapest Design		Highest Scoring Design		Feasibility Design		Customer Needs Design		Ease of Use and Comfort Design		Cost and Feasibility Design		Optimized Cost and Compatibility Design		All-Around Comfort and Compatibility Design	
		Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total	Score	Total
Comfort	0.15	4.75	0.7125	8	1.2	6	0.9	6.75	1.0125	7.5	1.125	6.25	0.9375	7.25	1.0875	8.25	1.2375
Easy Communication	0.14	6	0.84	7	0.98	6.5	0.91	9.5	1.33	9.5	1.33	6.75	0.945	8.75	1.225	9.5	1.33
Good Visibility	0.11	2.25	0.2475	8.75	0.9625	8.5	0.935	9	0.99	8.25	0.9075	8.25	0.9075	9	0.99	9	0.99
Easy Transport/Storage	0.06	9.25	0.555	7.75	0.465	7.75	0.465	6	0.36	5.75	0.345	6.25	0.375	6.75	0.405	7.5	0.45
Effective Filtration (Positive Pressure)	0.16	2	0.32	8.25	1.32	7.5	1.2	8.5	1.36	8.75	1.4	8.25	1.32	8.75	1.4	8.75	1.4
Reusable	0.06	5	0.3	7.25	0.435	7	0.42	7.25	0.435	6.5	0.39	6.75	0.405	7	0.42	7	0.42
Easy to Operate	0.06	9.25	0.555	6.25	0.375	6.25	0.375	5.5	0.33	5.5	0.33	6.75	0.405	5.25	0.315	5.5	0.33
Aesthetically Pleasing	0.02	6	0.12	5.5	0.11	5.25	0.105	5.5	0.11	5.5	0.11	4.75	0.095	5.5	0.11	5	0.1
Affordable	0.14	10	1.4	4.25	0.595	6	0.84	4	0.56	3.75	0.525	5.25	0.735	3	0.42	3.25	0.455
Accessibility	0.1	8.25	0.825	4	0.4	5	0.5	2.5	0.25	2.25	0.225	5.25	0.525	2.25	0.225	2.5	0.25
Total		**5.875**		**6.8425**		**6.65**		**6.7375**		**6.6875**		**6.65**		**6.5975**		**6.9625**	

Appendix [G]: Indented Bill of Materials

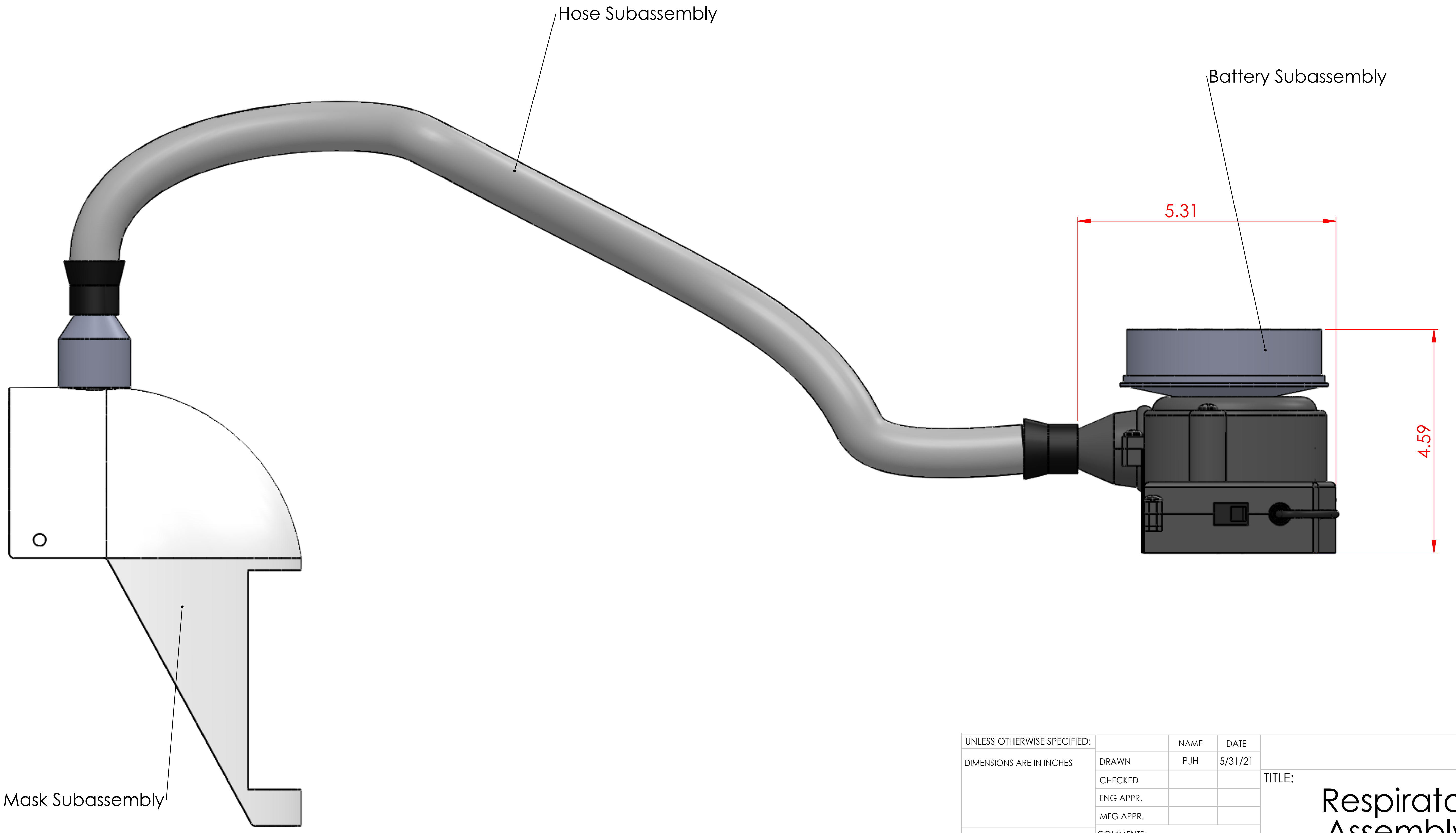
True Barrier Face Shield

Indented Bill of Material (iBOM)

Assembly Level	Part Number	Description	Qty	Cost	Ttl Cost	Source	More Info
		Lvl0 Lvl1 Lvl2 Lvl3					
0	100000	Final Assy	------	------	------	------	
1	110000	Face Mask	------	------	------	------	
2	111000	Snorkel Mask	1	$ 15.00	$ 15.00	Amazon.com	
1	120000	Hose	1	$ 8.99	$ 13.94	Amazon.com	
2	121000	Outlet Attachment (to mask)	1	-----	-----	custom	3D printed
2	122000	Hose Clamps	2	$ 1.99	$ 3.98	Ace Hardware	
1	130000	Blower	1	$ 9.99	$ 9.99	Amazon.com	
2	131000	Filter Inlet Attachment	1	-----	-----	custom	3D printed
3	131100	2-1/2" O-ring		$ 2.29	$ 2.32	Ace Hardware	
3	131200	1-5/8" O-ring	1	$ 1.39	$ 1.41	Ace Hardware	
3	131300	10/24 x 3/8" Screws	3	$ 0.23	$ 0.69	Ace Hardware	
1	140000	Battery	1	$ 32.99	$ 32.99	Amazon.com	
2	141000	Charger	1	-----	-----	Amazon.com	(included with battery)
2	142000	Cables	1	$ 4.50	$ 4.50	Amazon.com	pack of 2
2	143000	Wire crimp connectors	1	$ 0.80	$ 0.80	Ace	pack of 10
1	150000	Canister Filter	1	$ 19.88	$ 19.88	Zoro.com	Item G4564752
1	160000	Housing	1	-----	-----	custom	3D printed
2	161000	10/24 x 1/2" Screws	4	$ 0.26	$ 1.04	Ace Hardware	
2	162000	Belt clips	2	$ 1.99	$ 3.98	Amazon.com	
3	162100	1/8 x 1/4" Bolts	4	$ 0.15	$ 0.60	Ace Hardware	
3	162200	1/4" Washers	4	$ 0.14	$ 0.57	Ace Hardware	
3	162300	1/8" Nuts	4	$ 0.10	$ 0.40	Ace Hardware	
	Total Parts		**35**		**$112.09**		

Appendix [H]: Drawing Package

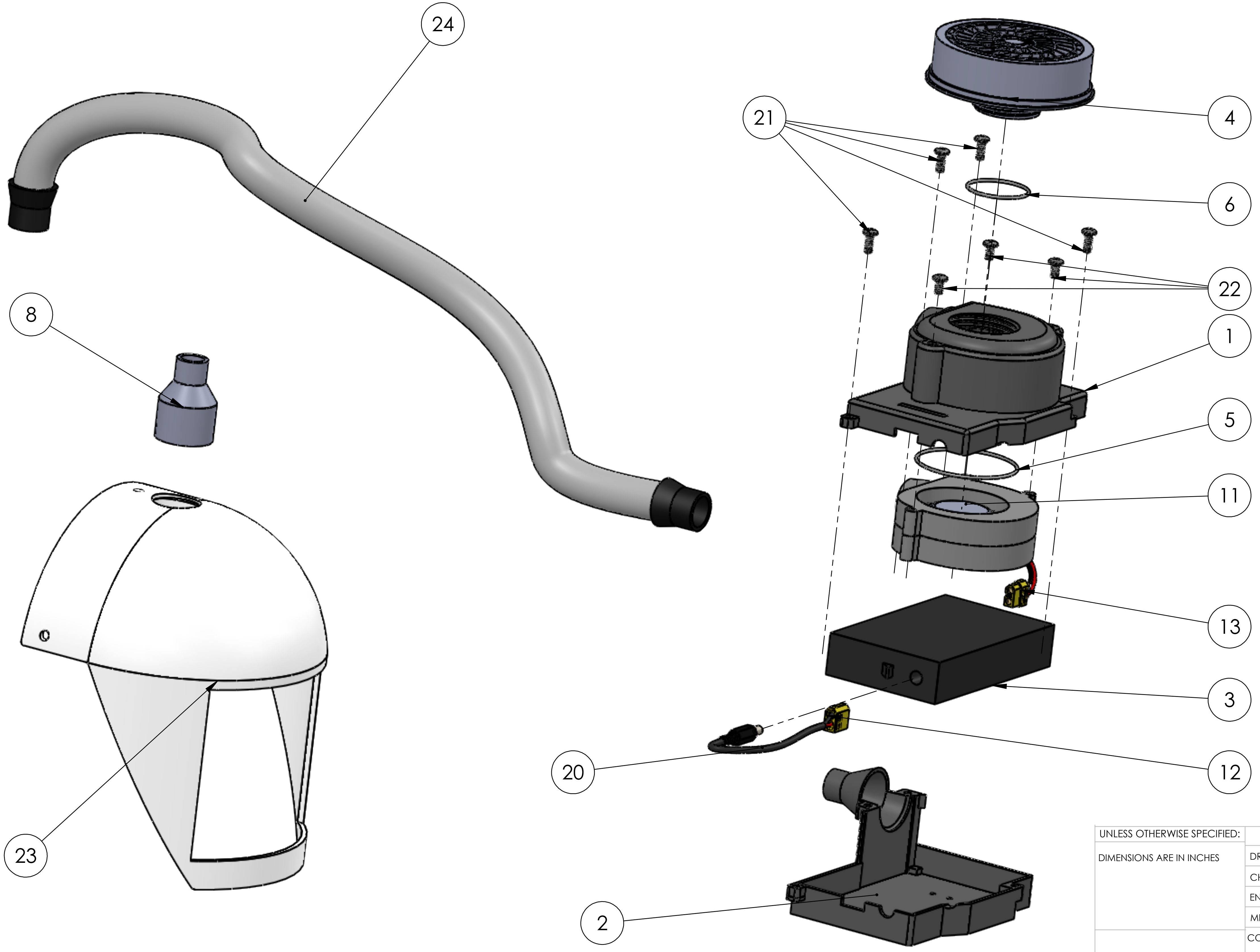
100: Open Shield Assembly
101: Exploded Open Shield Assembly
110: Shield Drawing
111: Shield Manifold Drawing
120: Hose-Shield Drawing
200: Sealed Assembly
201: Exploded Sealed Assembly
210: Snorkel Drawing
220: Hose-Snorkel Connector Drawing
300: Battery Pack Assembly
301: Exploded Battery Pack Assembly
310: Filter-Blower Connector Drawing
320: Blower-Hose Connector Drawing
330: 10/24 x ½ Screw Data Sheet
400: Hose Assembly



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	COMMENTS:		
MATERIAL			
DO NOT SCALE DRAWING			

TITLE:
Respirator Assembly

SIZE	DWG. NO.	REV
C	100	2
SCALE: 1:2		SHEET 1 OF 15



ITEM NO.	PART NUMBER	QTY.
1	Top Housing	1
2	Bottom Housing	1
3	Battery	1
4	Filter	1
5	2-1/2" Oring	1
6	1-5/8" Oring	1
8	Hose-Mask Connector	1
10	Blower	1
12	XT-60 Male	1
13	XT-60 Female	1
20	DC Power Cable	1
21	10-24 x 1/2" Screws	4
22	10-24 x 3/8" Screws	3
23	Sheild	1
24	Hose	1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES

	NAME	DATE
DRAWN	PJH	5/31/21
CHECKED		
ENG APPR.		
MFG APPR.		

COMMENTS:

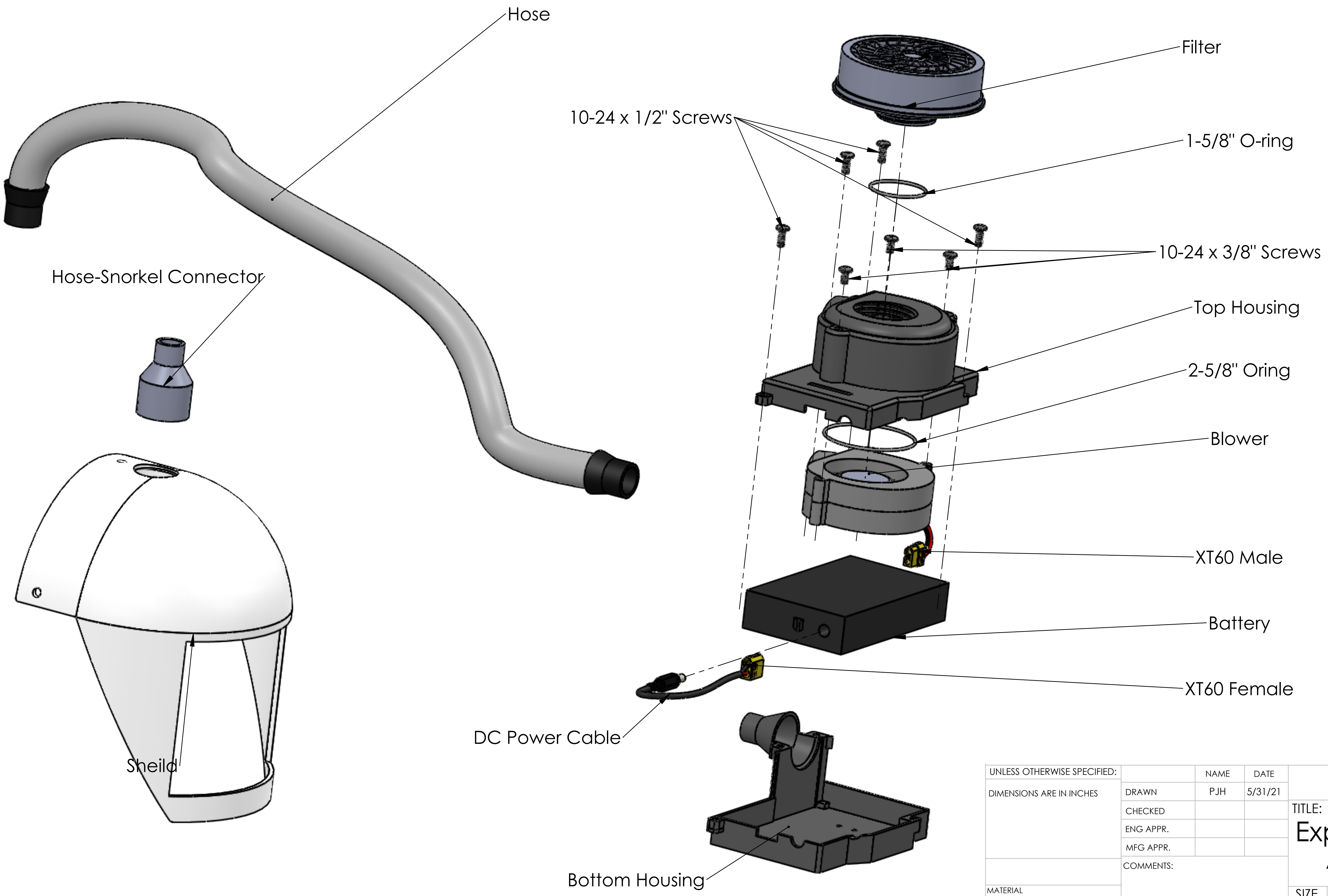
MATERIAL

DO NOT SCALE DRAWING

TITLE:

Exploded Respirator Assembly, BOM

SIZE C
DWG. NO. 101
REV 2
SCALE: 1:2.75
SHEET 2 OF 15



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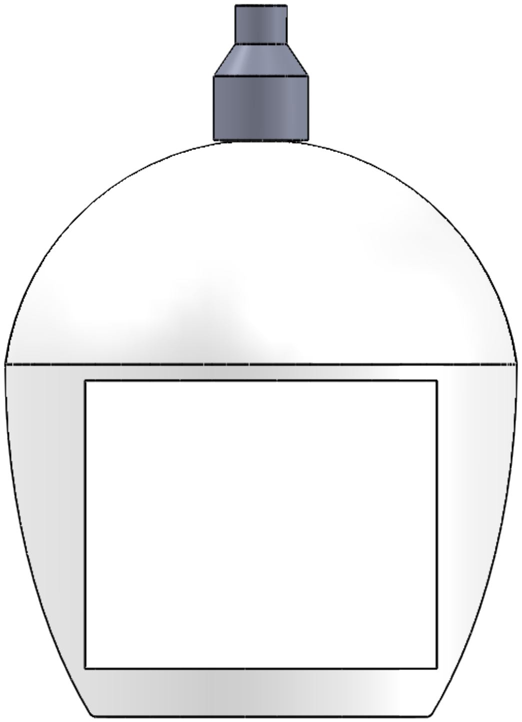
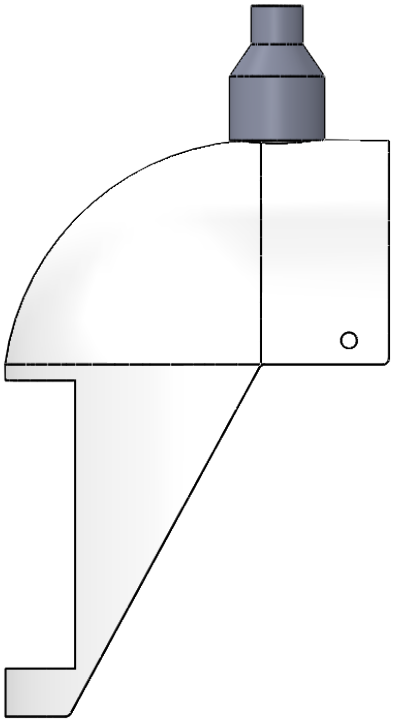
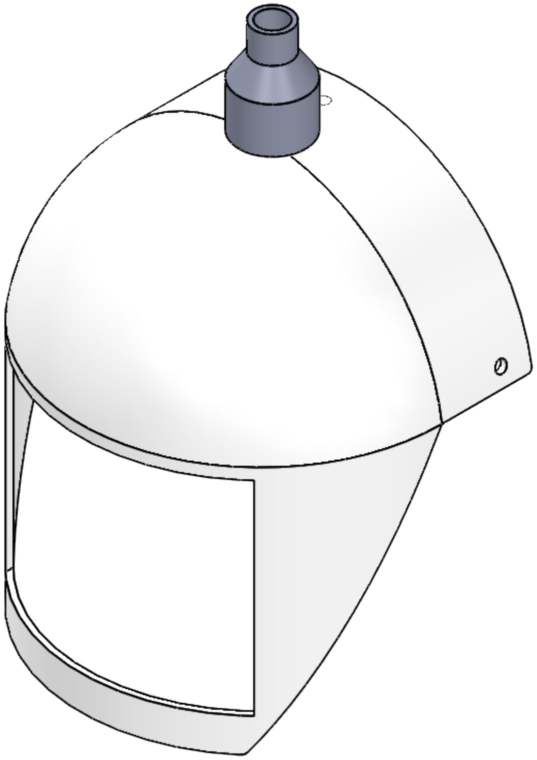
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
	COMMENTS:		
MATERIAL			
DO NOT SCALE DRAWING			

TITLE:
Exploded Respirator Assembly, Parts

SIZE	DWG. NO.	REV
C	102	1
SCALE: 1:10		SHEET 3 OF 15







		NAME	DATE
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		

MATERIAL

DO NOT SCALE DRAWING

COMMENTS: Note that this shield is not representative of the snorkel mask used in the design.

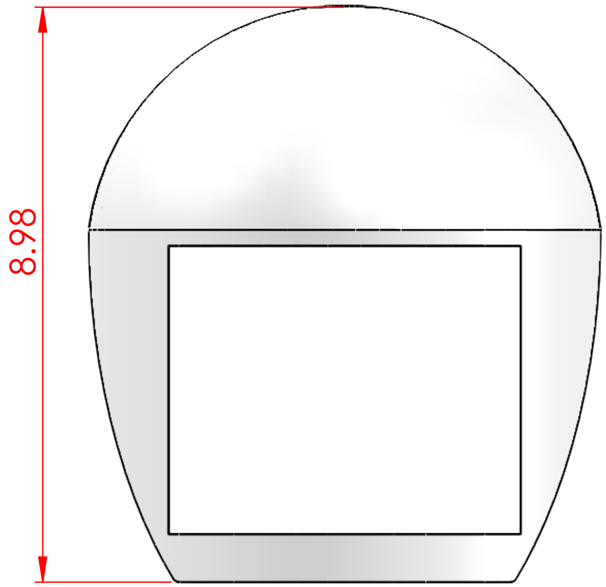
TITLE:

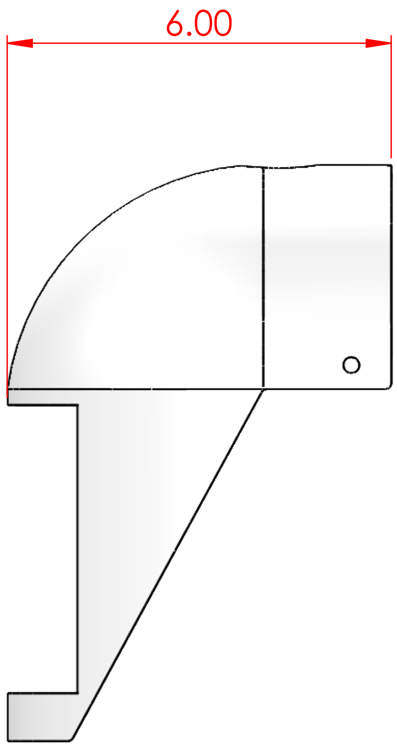
Face Shield Subassembly

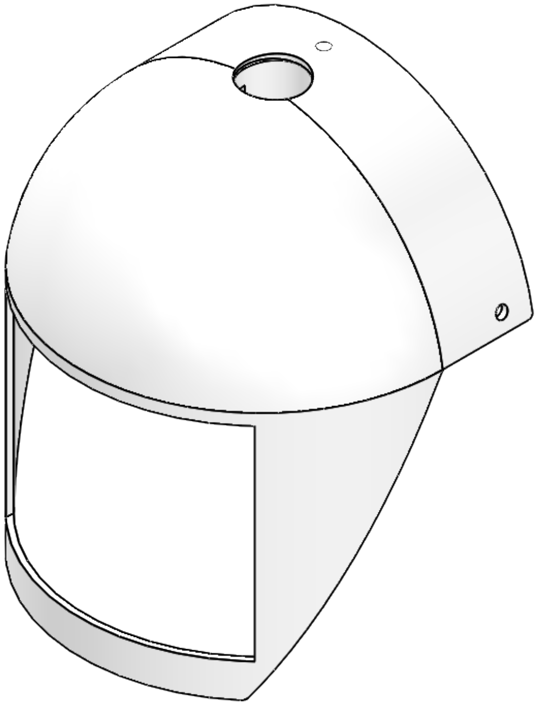
SIZE	DWG. NO.	REV
A	200	2

SCALE: 1:3

SHEET 4 OF 15







UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

MATERIAL

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	PJH	5/31/21
CHECKED		
ENG APPR.		
MFG APPR.		

COMMENTS: Note that this shield is not representative of the snorkel mask used in the design.

TITLE:

Face Shield

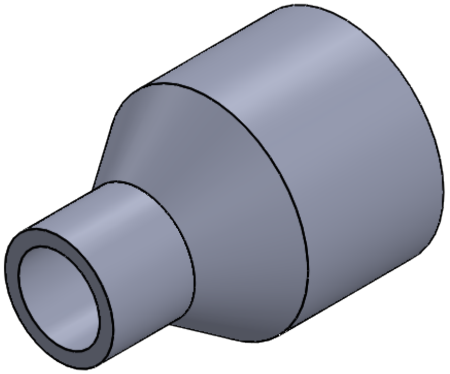
SIZE A

DWG. NO. 210

REV

SCALE: 1:3

SHEET 5 OF 15



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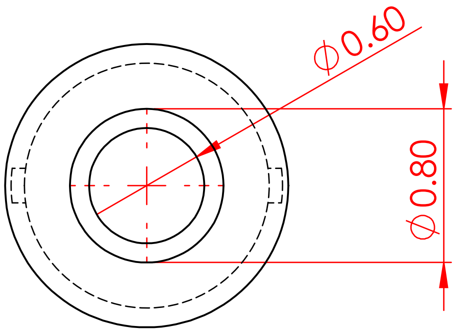

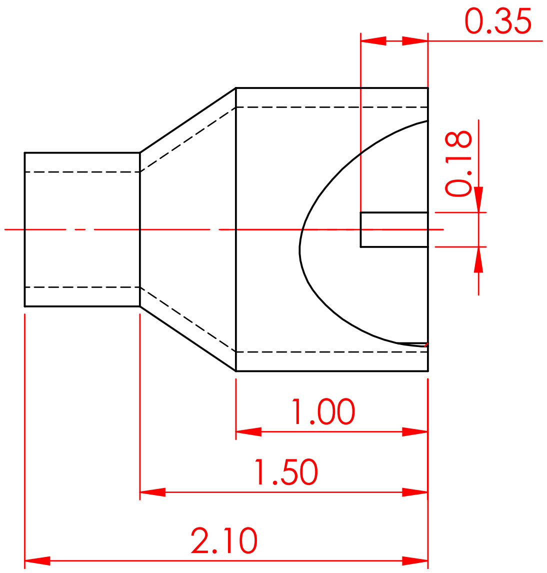

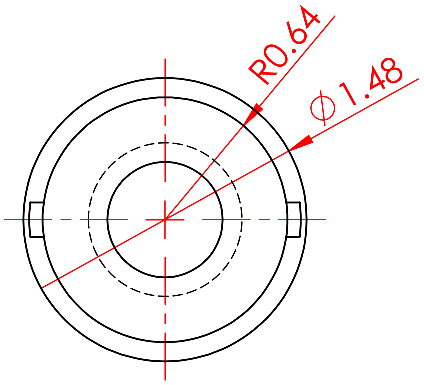

BACK

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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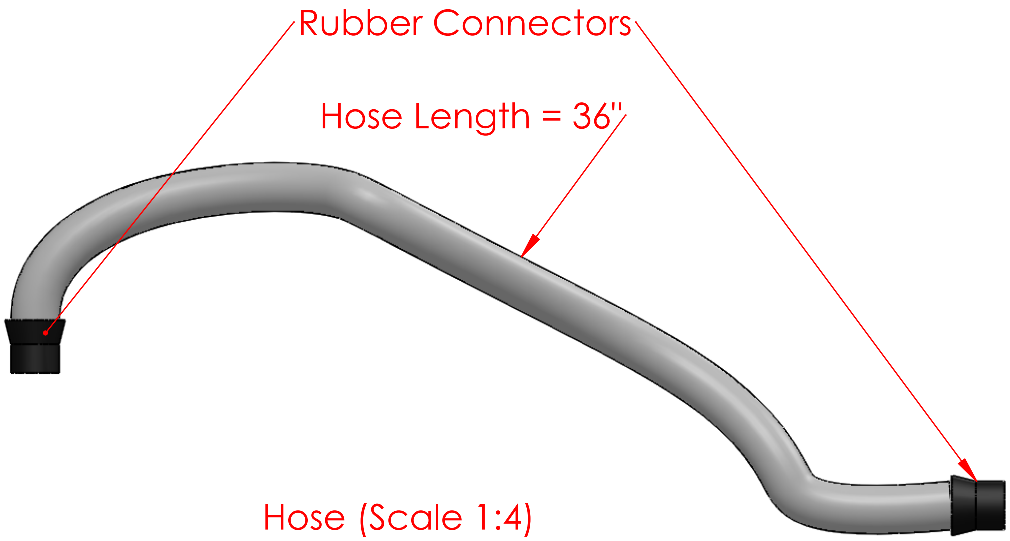
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL 3D Printed PLA	COMMENTS: To 3D print this part, please go to: https://www.thingiverse.com/thing:4876417		
DO NOT SCALE DRAWING			

TITLE:
Hose-Snorkel Connector

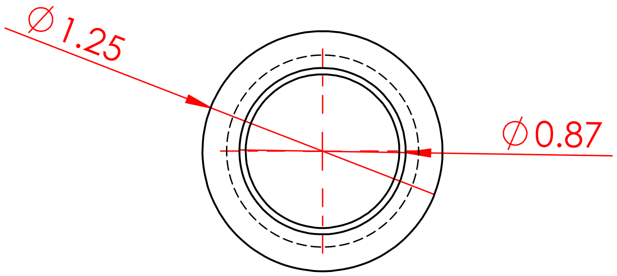
SIZE	DWG. NO.	REV
A	220	1
SCALE: 1:1		SHEET 6 OF 15

B



Hose (Scale 1:4)

Rubber Connector (Scale 1:1)



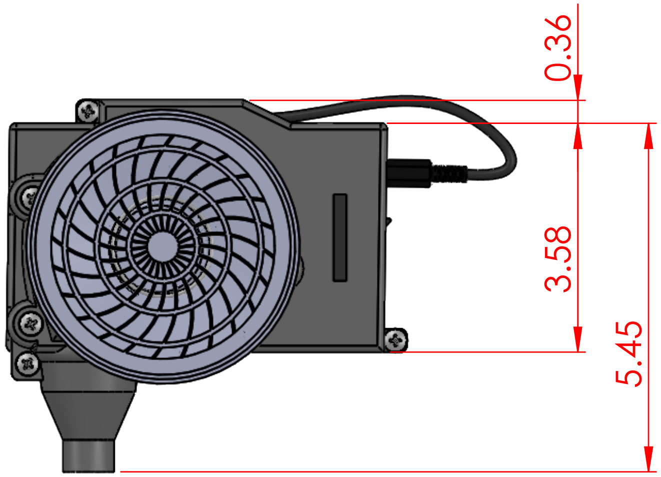
A

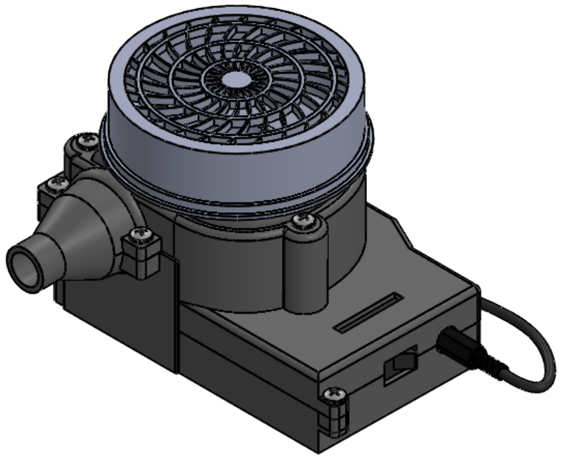
UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL	COMMENTS:		
DO NOT SCALE DRAWING			

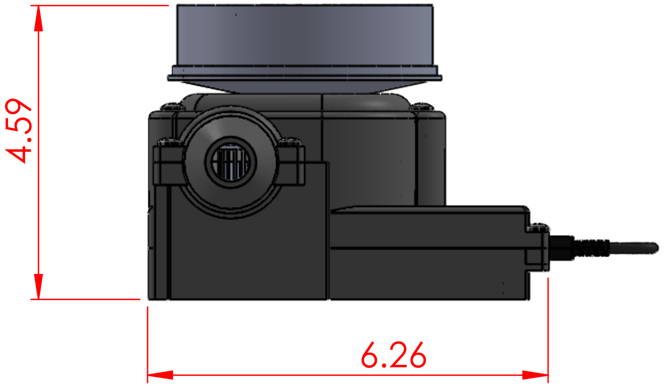
TITLE:

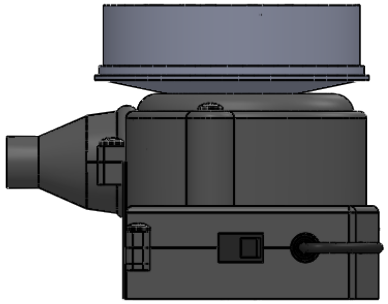
Hose Subassembly

SIZE	DWG. NO.	REV
A	300	
SCALE Varies		SHEET 7 OF 15

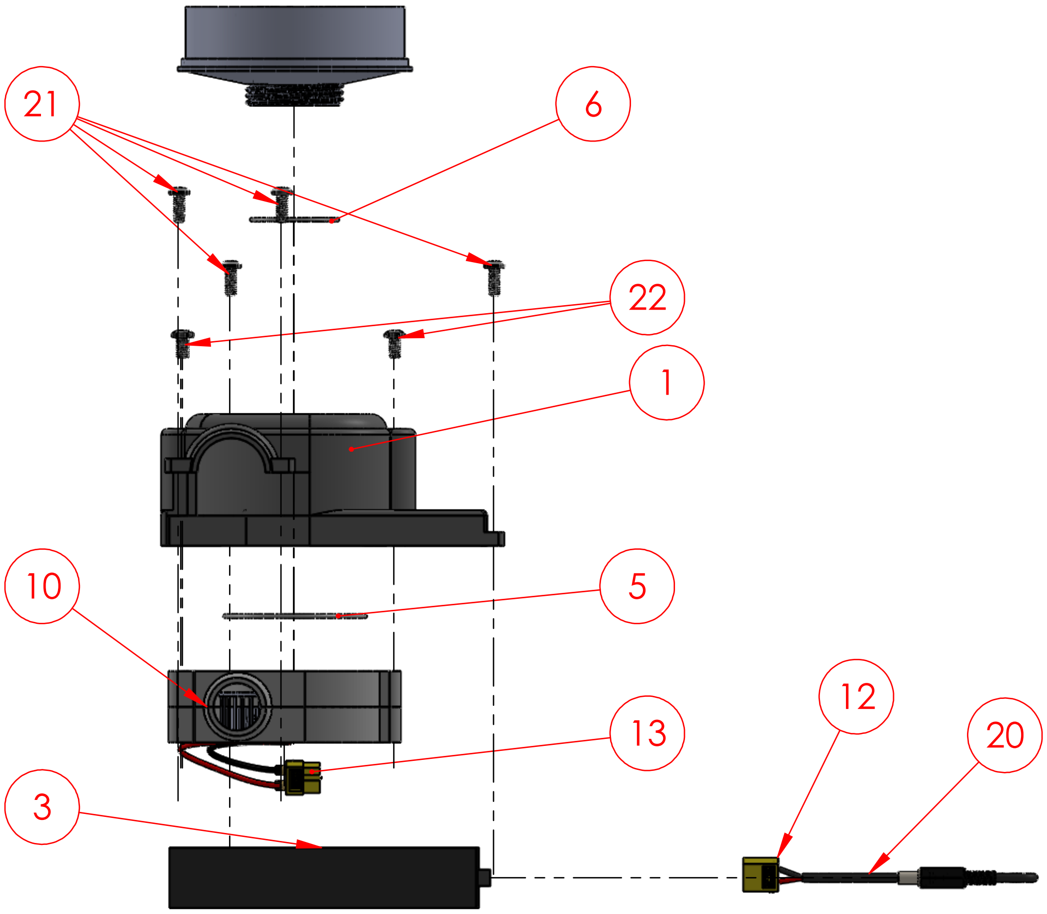




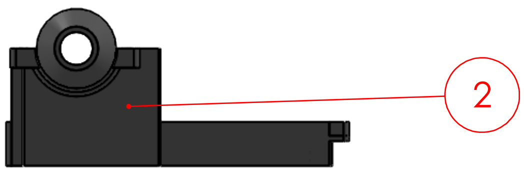




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21	
	CHECKED			TITLE:
	ENG APPR.			Battery Pack Subassembly
	MFG APPR.			
	COMMENTS:			
MATERIAL				SIZE A DWG. NO. 400 REV 2
DO NOT SCALE DRAWING				SCALE: 1:3 SHEET 8 OF 15



ITEM NO.	PART NUMBER	QTY.
1	Housing	1
2	Bottom Housing	1
3	Battery^Assembly	1
4	Filter	1
5	2-1/2" Oring	1
6	1-5/8" Oring	1
10	Blower	1
12	XT-60 Female	1
13	XT-60 Male	1
20	DC Power Cable	1
21	10-24 x 1/2" Screws	4
22	10-24 x 3/8" Screws	3
23	Sheild	1



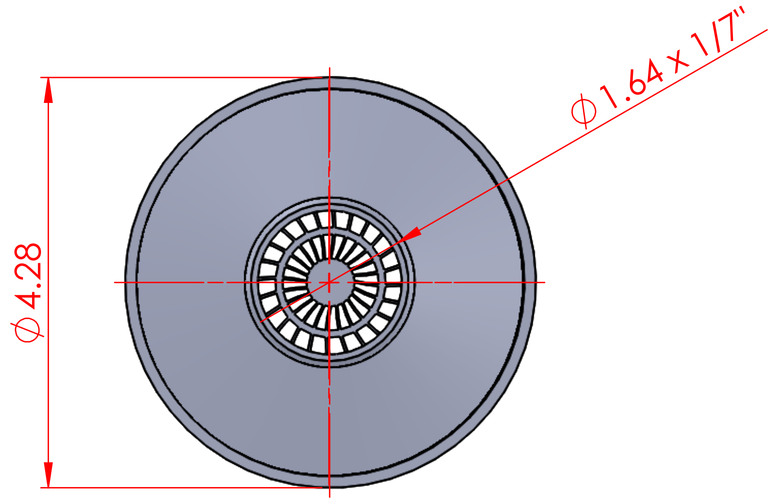
		NAME	DATE
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL	COMMENTS:		
DO NOT SCALE DRAWING			

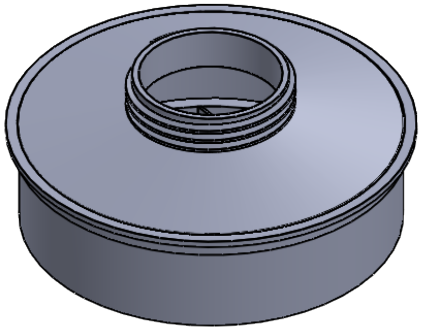
TITLE:

Exploded Battery Pack Subassembly

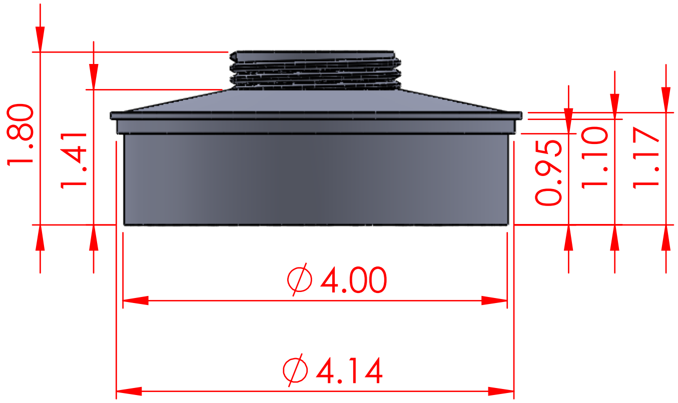
SIZE A
DWG. NO. 401
REV 2
SCALE: 1:3.5
SHEET 9 OF 15

B





A

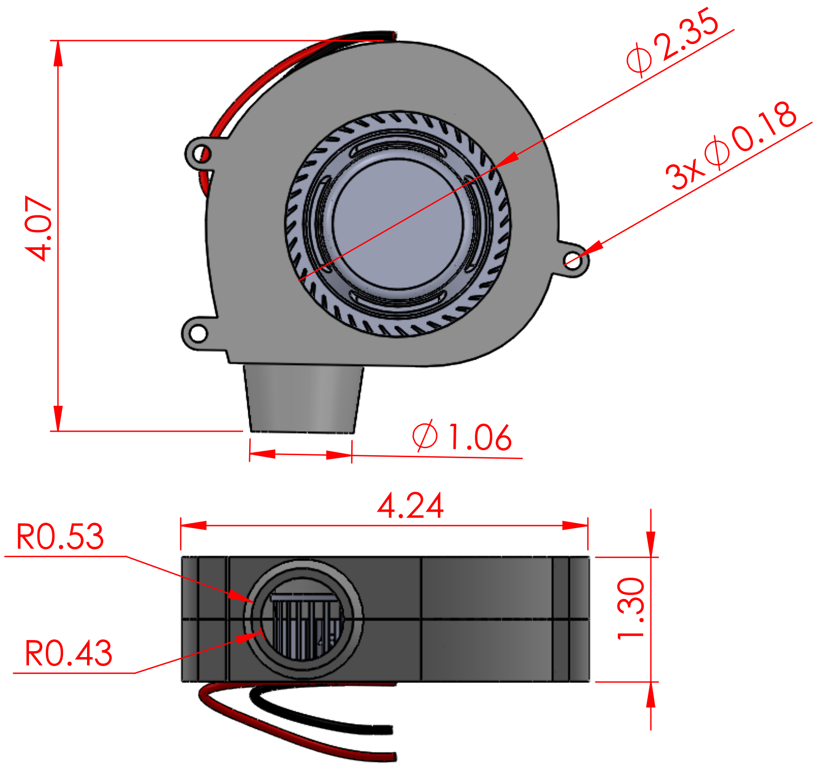


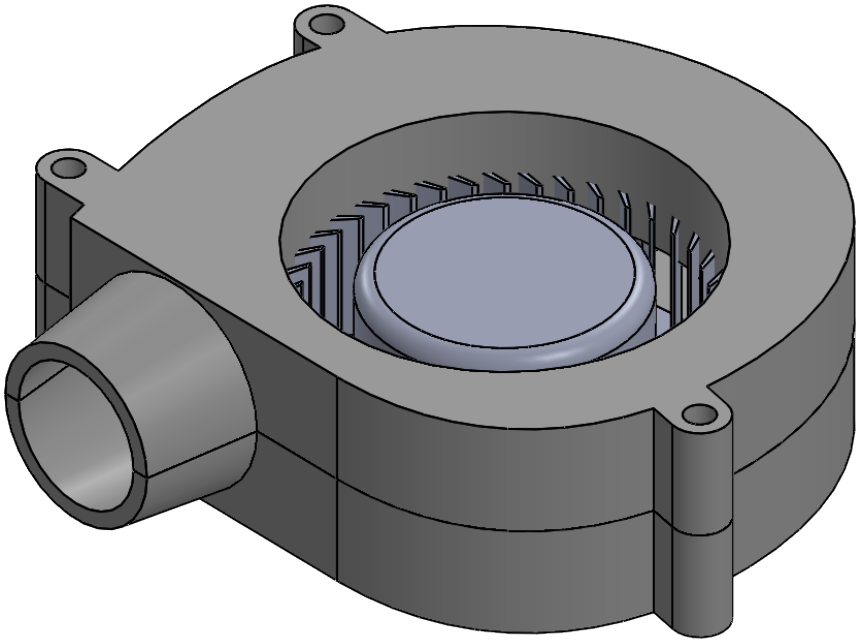
		NAME	DATE
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL	COMMENTS:		
DO NOT SCALE DRAWING			

TITLE:

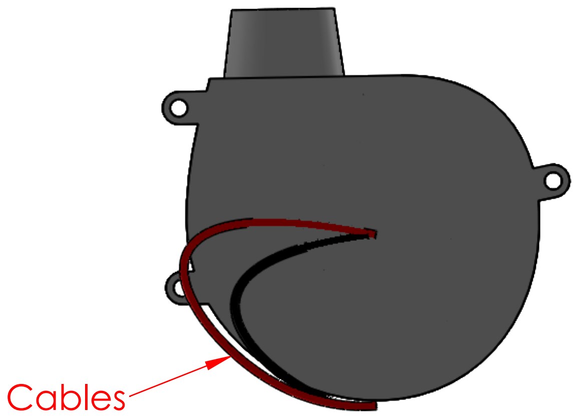
Filter

SIZE	DWG. NO.	REV
A	410	1
SCALE: 1:2		SHEET 10 OF 15





Scale 1:1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL	COMMENTS:		
DO NOT SCALE DRAWING			

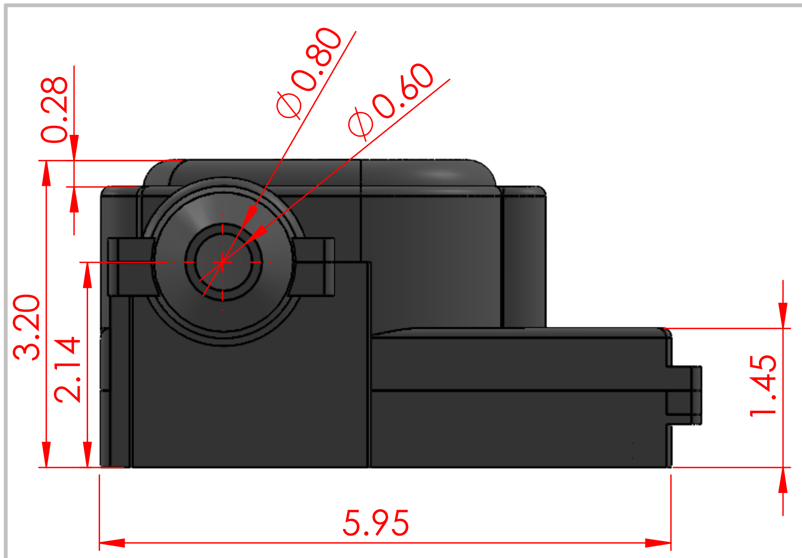
TITLE:

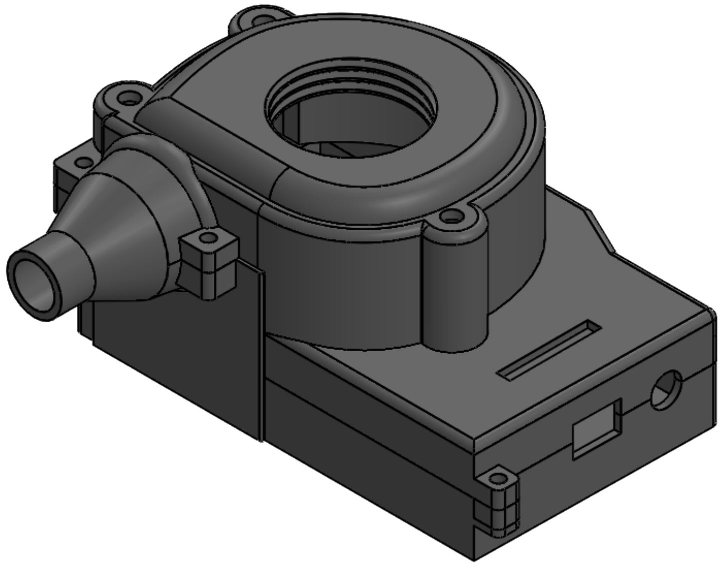
Blower

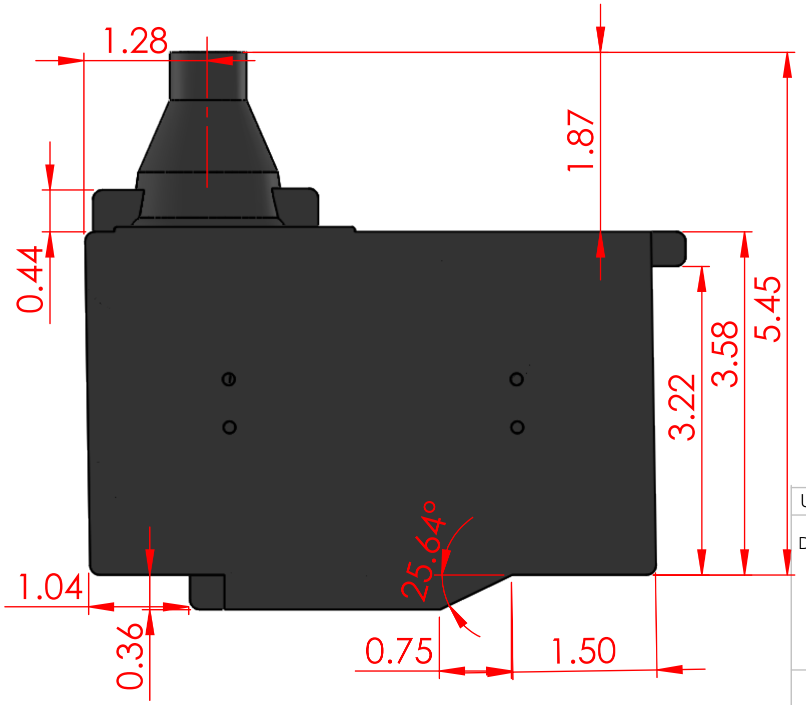
SIZE	DWG. NO.	REV
A	420	1

SCALE: 1:2

SHEET 11 OF 15







UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

	NAME	DATE
DRAWN	PJH	5/31/21
CHECKED		
ENG APPR.		
MFG APPR.		

COMMENTS: To 3D print this part, please go to:

https://www.thingiverse.com/thing:4876417

MATERIAL

3D Printed PLA

DO NOT SCALE DRAWING

TITLE:

Housing Subassembly

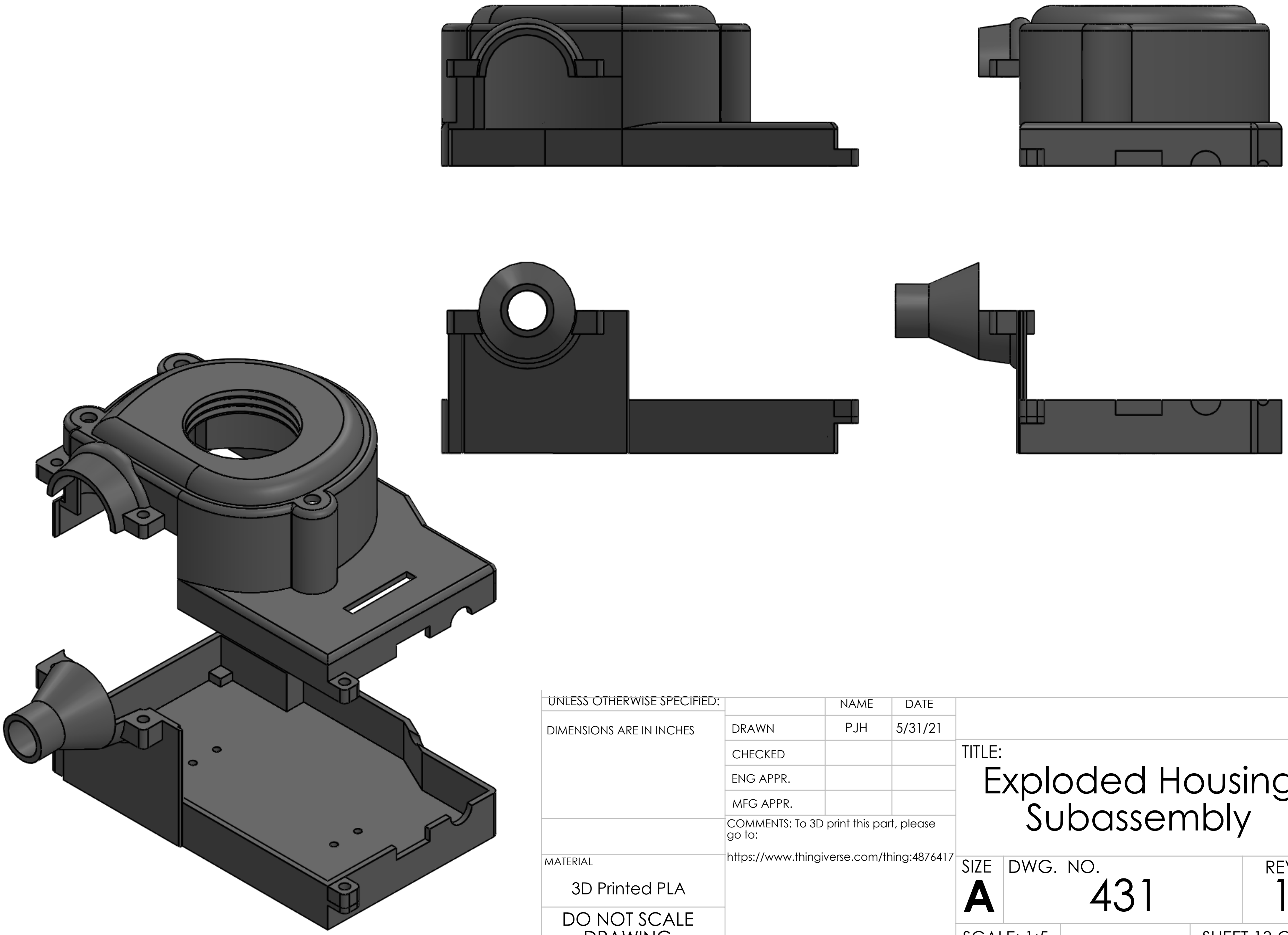
SIZE **A**

DWG. NO. 430

REV 1

SCALE: 1:2

SHEET 12 OF 15

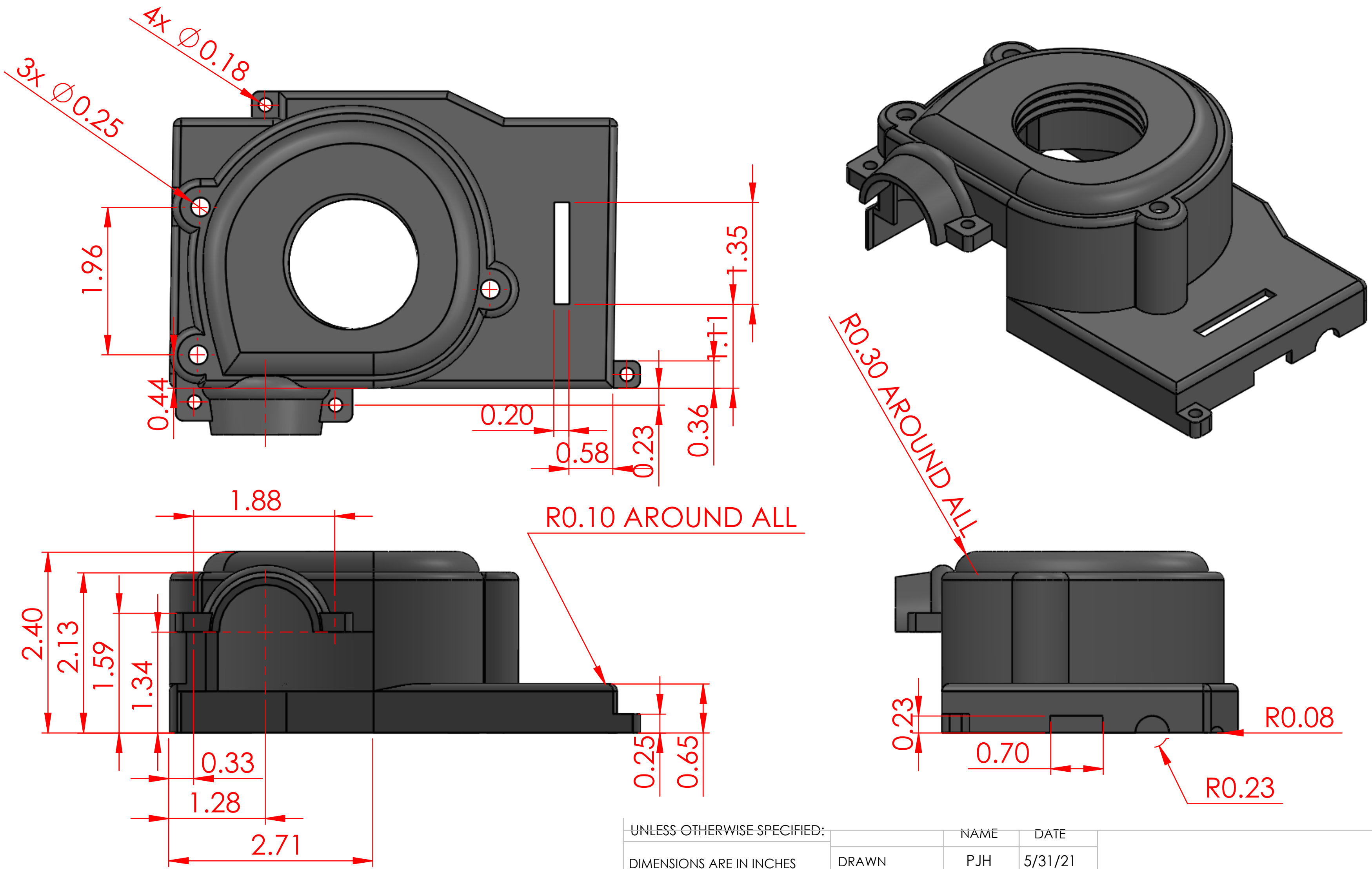


UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		
MATERIAL 3D Printed PLA	COMMENTS: To 3D print this part, please go to: https://www.thingiverse.com/thing:4876417		
DO NOT SCALE DRAWING			

TITLE:

Exploded Housing Subassembly

SIZE	DWG. NO.	REV
A	431	1
SCALE: 1:5		SHEET 13 OF 15



UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

	NAME	DATE
DRAWN	PJH	5/31/21
CHECKED		
ENG APPR.		
MFG APPR.		

COMMENTS: To 3D print this part, please go to:

https://www.thingiverse.com/thing:4876417

MATERIAL

3D Printed PLA

DO NOT SCALE DRAWING

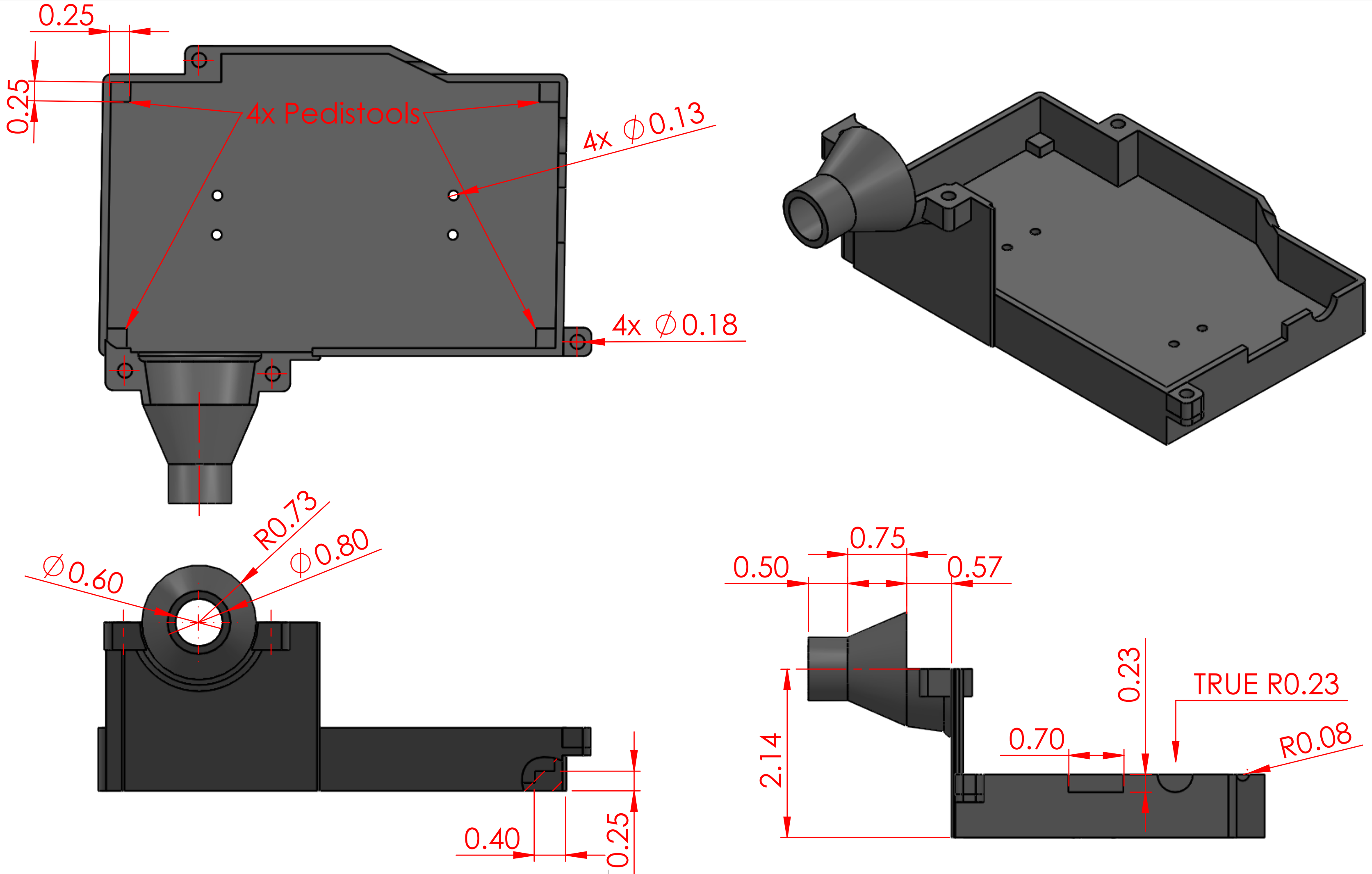
TITLE:

Top Housing

SIZE	DWG. NO.	REV
A	432	1

SCALE: 1:2

SHEET 14 OF 15



		NAME	DATE
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES	DRAWN	PJH	5/31/21
	CHECKED		
	ENG APPR.		
	MFG APPR.		

COMMENTS: To 3D print this part, please go to:

https://www.thingiverse.com/thing:4876417

MATERIAL

3D Printed PLA

DO NOT SCALE DRAWING

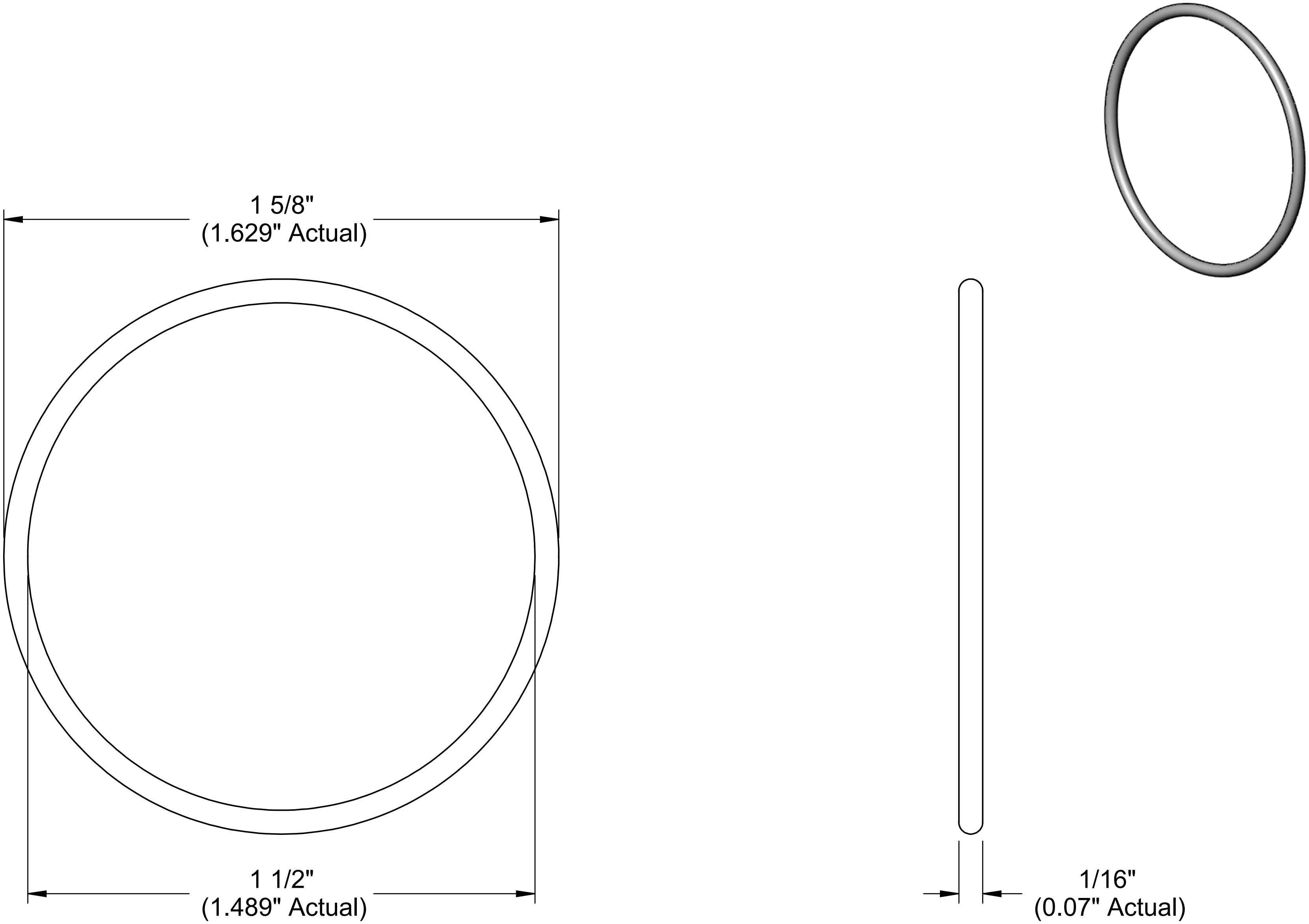
TITLE:

Bottom Housing

SIZE	DWG. NO.	REV
A	433	1

SCALE: 1:2

SHEET 15 OF 15

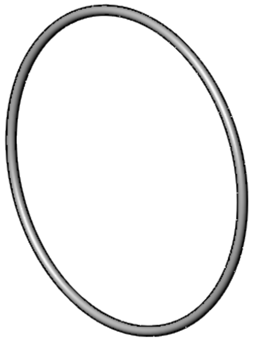


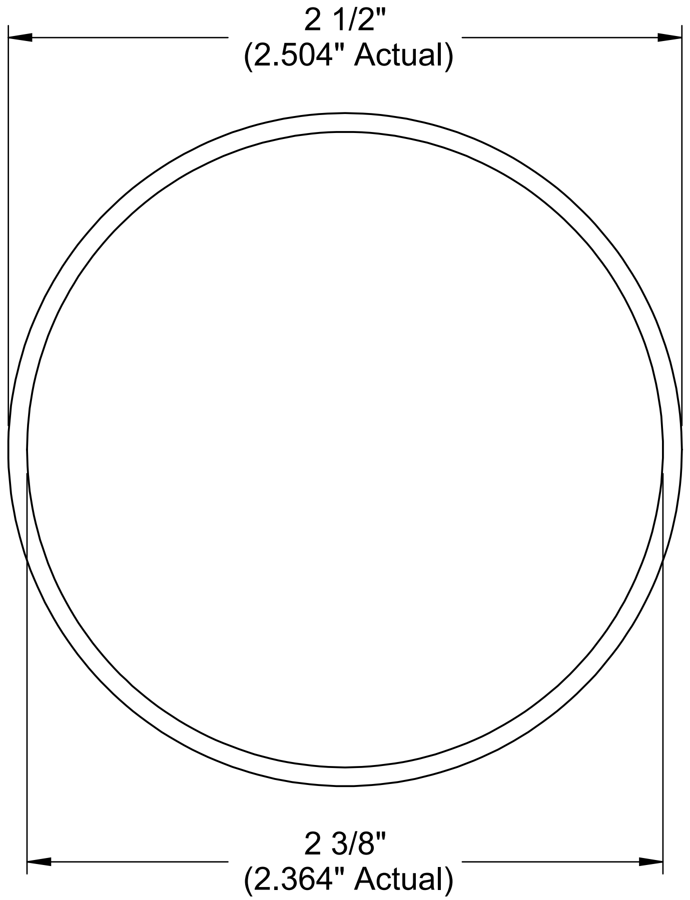
McMASTER-CARR® CAD

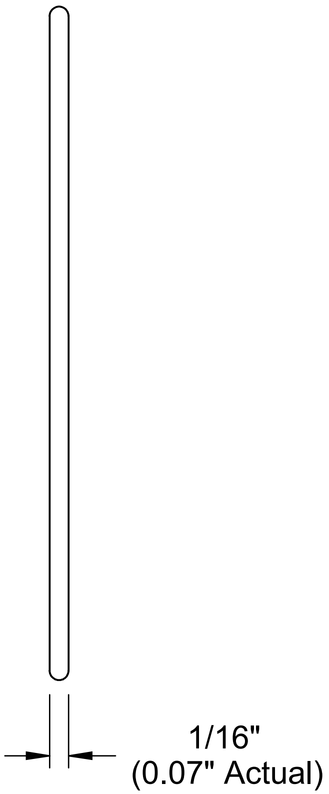
DRAWING NUMBER **440**

http://www.mcmaster.com

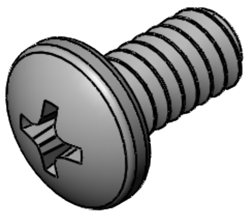
Abrasion-Resistant
O-Ring

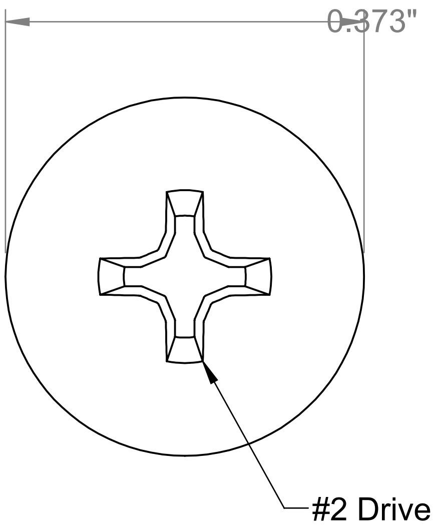


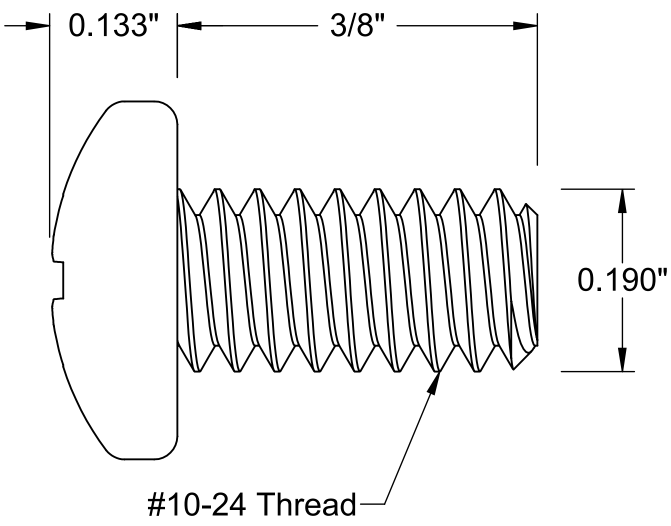




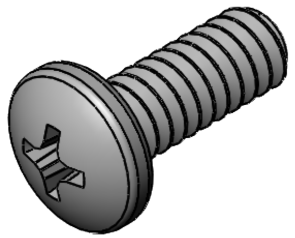
McMASTER-CARR® CAD	DRAWING NUMBER	450
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Abrasion-Resistant O-Ring	

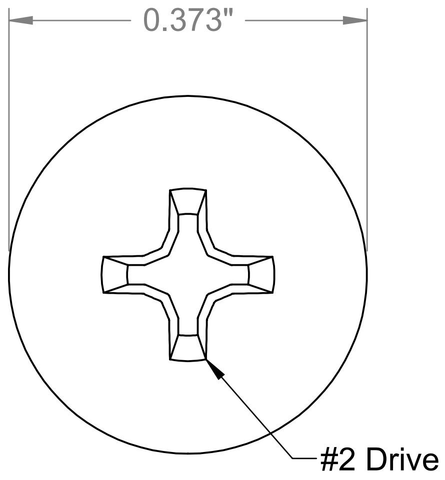


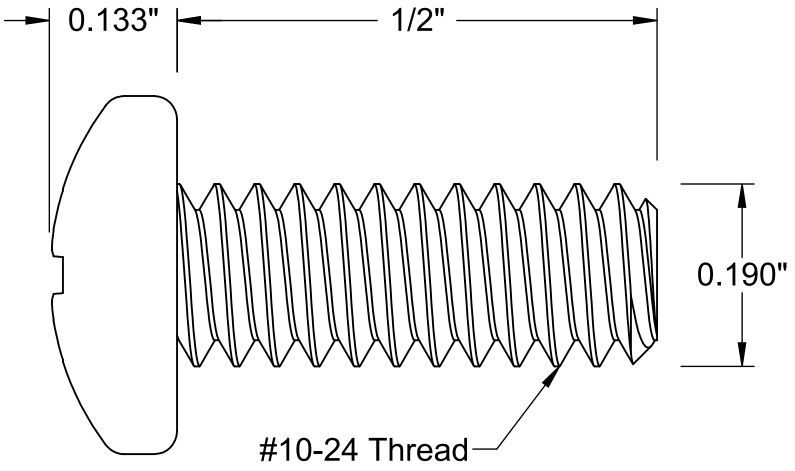




McMASTER-CARR® CAD	DRAWING NUMBER	460
http://www.mcmaster.com © 2012 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Pan Head Phillips Machine Screw	







McMASTER-CARR® CAD

DRAWING NUMBER **470**

http://www.mcmaster.com

Pan Head Phillips
Machine Screw

Product leaflet

Product	**Model No.**	**Ordering No.**
Particulate filter HE	SR 710	H02-1521

Product Description

The SR 710 particulate filter is provided with a special thread and is designed for use in the Sundström SR 500 Powered Air-Purifying Respirator (PAPR) as a separate particulate filter, i.e. it cannot be combined with a chemical cartridge. The filter is of HE type and provides protection against all types of particulate pollutants. If a combined filter for PAPR SR 500 is needed, the chemical cartridge should be combined with the SR 510 particulate filter.

Overview of particulate filter

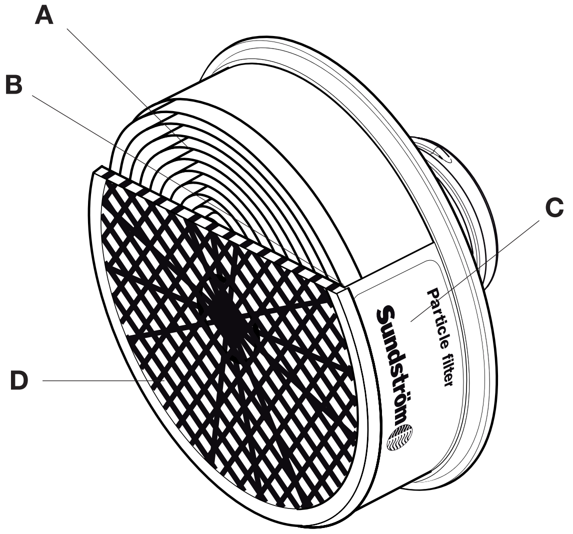
Model	**Application**
SR 510	SR 90-2, SR 90-3, SR 100, SR 200, PAPR SR 500
SR 710	PAPR SR 500

See separate product leaflets.

Technical specification

	SR 710	**42 CFR part 84**
Pressure drop at 30 l/min	≈ 40 Pa	-
Pressure drop at 95 l/min	≈ 120 Pa	-
Diameter/height	4.3/1.9 inch (108/48 mm)	-
Thread	44 x 1/7”	-
Weight	2.5 oz (70 g)	-
Service temperature	14 to 131 °F (-10 to +55 °C), < 90 % RH	-
Storage temperature	4 to 104 °F (-20 to +40 °C), < 90 % RH	-
Filtration efficiency, DOP	> 99.997 %	≥ 99.97 %
Approval	NIOSH 42 CFR part 84	

- **A. Filter medium**
- **B. Hot-melt adhesive**
- **C. Marking label**
- **D. Filter canister**



Sundstrom Safety Inc.
20 North Blossom St.
East Providence, RI 02914
Office: 1-401-434-7300
Toll Free: 1-877-SUNDSTROM
Fax: 1-401-434-8300
info@srsafety.com
www.srsafety.com

Sundström®
www.srsafety.com

Blower Specification Sheet

Model	YB1206000	**Capacity**	11.1V 6000mAh
Input	12.6V/3A Max	**Weight**	About 370g
Output	12V (voltage range is 12.6-9V)/3A Max		

DC Cable Specification Sheet

Model Number	US-CAB-29	**Dimensions**	9.84 x 0.39 x 0.39 inches
Input	12V - 24V	**Weight**	0.176 ounces

High Quality Gold Plated XT60 Male & Female Bullet Connector

SKU:FIT0587

INTRODUCTION

This is a CE-certified XT60 plug that is mini-sized .The plug features a true gold plating and a banana cross recessed design with a larger contact area that can withstand a constant 30A peak current of 60A.Its plastic casing is made of insulating material, and its flame retardant grade has reached UL94 V0. It is not easy to burn after fire, and it is automatically extinguished when it leaves the fire source.The internal banana insert and the plastic case are integrally casted, and the combination is tight and resistant to plugging.At the same time, it adopts the design of special-shaped sheath, groove card slot, non-slip plug and waterproof steam, and has humanized welding joint, which has high integration degree and is convenient for welding and plugging.

FEATURES

- Non-flammable, low resistance, mini size

SPECIFICATION

- Type:XT60
- Rated voltage:DC500V
- Rated current: 30A
- Instantaneous current: 60A
- Insulation shell material: PA
- Metal head material: copper plated
- Flame retardant rating: UL94 V0
- Recommended wire gauge: 12AWG
- Contact resistance: 0.55 milliohm
- Number of uses: 1000 times
- Working environment temperature: -20 ° C ~ 120 ° C
- Safety certification: UL/CE

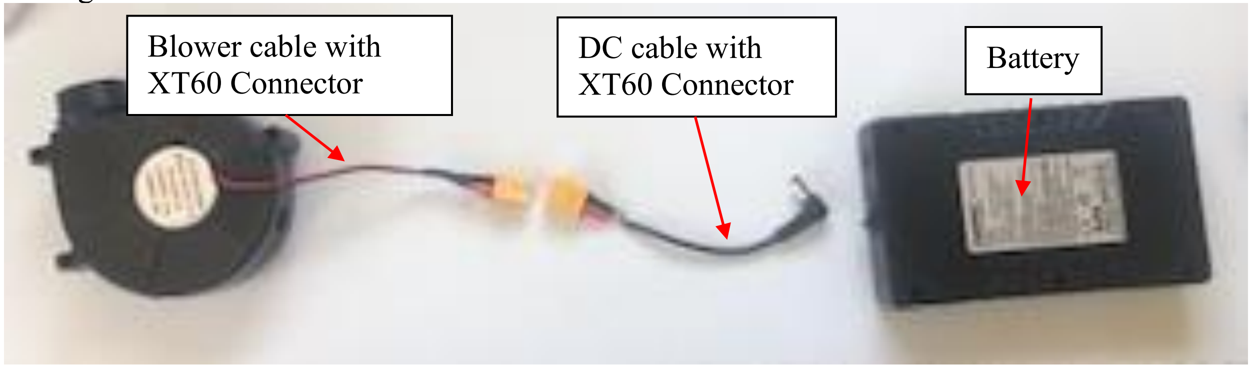
SHIPPING LIST

- High Quality Gold Plated XT60 Male & Female Bullet Connector x1

https://www.dfrobot.com/product-1763.html 8-7-18

Appendix [I]: Electrical Schematics

Wiring disassembled:



Wiring re-assembled:

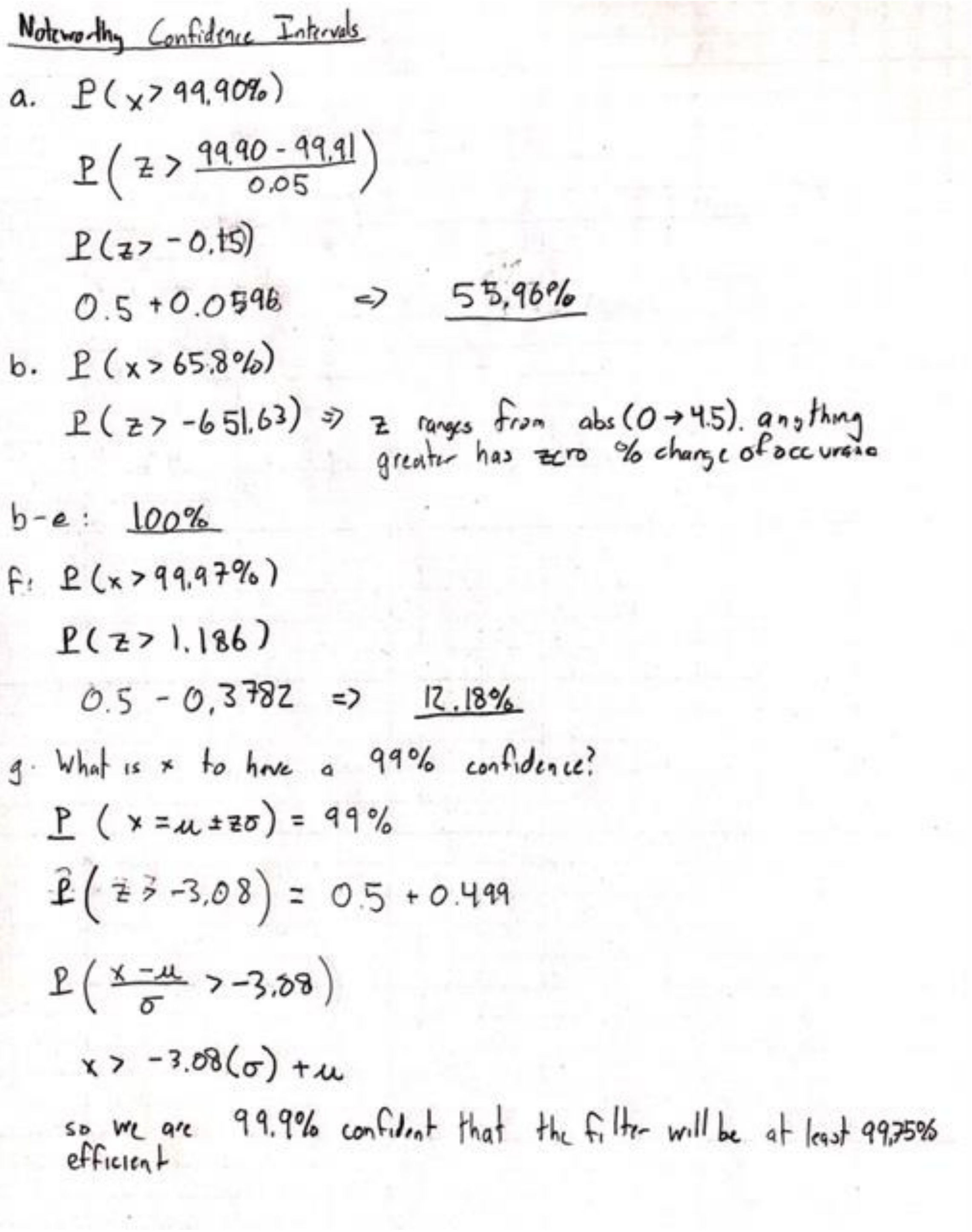
Appendix [J]: Final Project Budget

PURCHASES TO DATE

Vendor	Product Name	Part Number	Product Hyper Link	Qty	Price/Ea	Shipping	Total	Notes
Amazon	Fugetek 12V DC Brushless Blower		Fugetek - Amazon	1	$9.99	$0.00	$9.99	
Amazon	AC Infinity Multifan S1		AC Infinity Fan - Amazon	1	$10.99	$0.00	$10.99	
Amazon	E-outstanding Fan Regulator		Fan Regulator - Amazon	1	$5.99	$0.00	$5.99	
Amazon	Jackson Safety MAXVIEW Face Shield		MAXVIEW Face Sheild - Amazon	1	$37.95	$0.00	$37.95	
Amazon	Bluemoona Belt Clip		Holster Belt Clips - Set of 4	1	$7.99	$0.00	$7.99	
Amazon	I clean Dyson Hose		Dyson Hose	1	$15.60	$0.00	$15.60	
Amazon	CPAP Hose Original Universal Hose		CPAP Hose	1	$7.99	$0.00	$7.99	
Amazon	(Black/SmallMedium) Iferror Full Face Snorkel Mask		Snorkel Mask	1	$9.99	$0.00	$9.99	
Zoro	PAPR HE Filter, Threaded, Particulates, Magenta, Niosh Approved	G4564752	Filter	1	$39.75	$5.00	$44.75	
Amazon	Gocheer snorkel mask (small)		Gocheer snorkel mask-amazon-small	1	$15.99	$0.00	$15.99	
Amazon	Gocheer snorkel mask (large)		Gocheer snorkel mask-amazon-large	1	$15.99	$0.00	$15.99	
Amazon	SparkFun Blower (12V)		SparkFun Blower	1	$10.50	$0.00	$10.50	
Amazon	Workshop Vacuum Accessories (hose and cuffs)		Workshop Hose	1	$32.14	$0.00	-	RETURNED
Amazon	Cen-Tec Hose		Cen-tec hose	1	$29.94	$0.00	$29.94	
Amazon	X211 Knife Blade		X-acto Knife Blade	1	$6.08	$0.00	$6.08	
Amazon	Silicon Rubber Sheet		Silicon Rubber Sheet	1	$11.85	$0.00	$11.85	
Amazon	Electric Matress air Pump		Air Pump	1	$19.59	$0.00	$19.59	
Amazon	PLA Filament		PLA Filament	2	$19.99	$0.00	-	RETURNED
Amazon	DollaTek DC Motor Speed Control Variable Voltage Regulator		Voltage Regulator	1	$7.99	$0.00	$7.99	
Amazon	SparkFun Blower (12V)		SparkFun Blower	1	$10.50	$0.00	-	RETURNED
Amazon	Grey Standard CPAP tubing		Grey CPAP Hose	1	$12.52	$0.00	$12.52	
Amazon	White CPAP tubing (3ft)		White CPAP Hose	1	$8.99	$4.95	$13.94	
Amazon	BEPHOLAN Pro Rubber Training Head Mannequin		BEPHOLAN Pro Rubber Mannequin	1	$0.00	$9.59	$9.59	
Amazon	Talentcell Rechargeable Battery 6000mAh Li-ion Battery Pack		Talentcell Battery	1	$0.00	$32.99	$32.99	
Amazon	FolioGadgets 10-Pack Male DC 2.1mmx 5.5mm Wire Power Adapters		FolioGadget Adapters	1	$0.00	$4.99	$4.99	
Amazon	SparkFun Blower (12V)		SparkFun Blower	1	$0.00	$14.68	$14.68	
Amazon	Sterilite 19324306 Gasket Box See-Through Lid and Base with Blue Aquarium Latches and Gasket, 20-Quart, 6-Pack		Sterilite Gasket Boxes, 6-Pack	1		$69.69	$69.69	
Amazon	3D Printer PLA Filament 1.75,SUNLU Black PLA 1.75mm of MasterSpool,Fit FDM 3D Printer,1KG Spool,Pack of 2, Dimensional Accuracy +/- 0.02 mm,PLA White+Red		3D Printer PLA Filament, 2-Pack	1		$31.99	$31.99	
						TOTAL	$459.56	

EXPENSES	
CURRENT PURCHASE EXPENSES	$459.56
EXPENSES IN PROGRESS	$0.00
ASSUME TAX IS 7.75% (SLO SALES TAX)	$35.62
TOTAL EXPENSES	$495.18
PROJECT BUDGET	$3,000.00
BUDGET REMAINING	$2,504.82

Appendix [K]: Noteworthy Confidence Intervals Hand Calculation



Noteworthy Confidence Intervals

a. $P(x > 99.90\%)$

$$P\left(z > \frac{99.90 - 99.91}{0.05}\right)$$

$P(z > -0.15)$

$0.5 + 0.0596 \Rightarrow \underline{55,96\%}$

b. $P(x > 65.8\%)$

$P(z > -651.63) \Rightarrow$ z ranges from abs$(0 \rightarrow 4.5)$. anything greater has zero % change of occurance

b-e: $\underline{100\%}$

f: $P(x > 99.97\%)$

$P(z > 1.186)$

$0.5 - 0,3782 \Rightarrow \underline{12.18\%}$

g. What is x to have a 99% confidence?

$P(x = \mu \pm z\sigma) = 99\%$

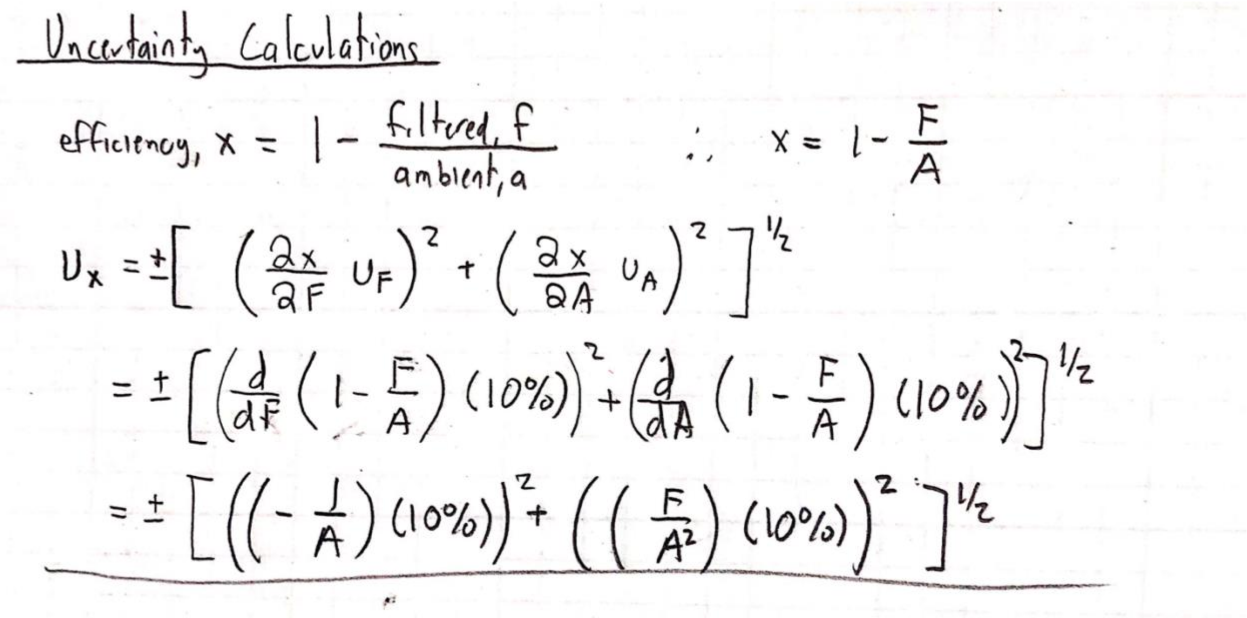
$\hat{P}(z > -3,08) = 0.5 + 0.499$

$$P\left(\frac{x - \mu}{\sigma} > -3.08\right)$$

$x > -3.08(\sigma) + \mu$

so we are 99.9% confident that the filter will be at least 99.75% efficient

Appendix [L]: Uncertainty Propagation Hand Calculations



Uncertainty Calculations

efficiency, $x = 1 - \frac{\text{filtered, f}}{\text{ambient, a}}$ $\therefore$ $x = 1 - \frac{F}{A}$

$$U_x = \pm\left[\left(\frac{\partial x}{\partial F}\,U_F\right)^2 + \left(\frac{\partial x}{\partial A}\,U_A\right)^2\right]^{1/2}$$

$$= \pm\left[\left(\frac{d}{dF}\left(1-\frac{F}{A}\right)(10\%)\right)^2 + \left(\frac{d}{dA}\left(1-\frac{F}{A}\right)(10\%)\right)^2\right]^{1/2}$$

$$= \pm\left[\left(\left(-\frac{1}{A}\right)(10\%)\right)^2 + \left(\left(\frac{F}{A^2}\right)(10\%)\right)^2\right]^{1/2}$$

Appendix [M]: Failure Modes & Effects Analysis

Product: True Barrier Face Respirator
Team: F62

Design Failure Mode and Effects Analysis

Prepared by: Jomil Aquipel
Date: 11/20/2020 (orig)

Failure Modes and Effects Analysis

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
Provides the energy to move filtered air to the user (Fan/Battery/Backpack)	Battery breaks/stops working	Not enough airflow to user	6.5	1. Battery breaks 2. Battery overheats	1. Power required analysis 2. reading through battery specifications	3	1. test time it takes to charge battery	1	19.50						
	Insufficient battery life	Not enough airflow to user	5.0	1. battery not rated high enough for design	1. reading through battery specifications	2	1. test battery life	1	10.00						
Components are of a reasonable weight and are placed in a balanced position	Fan is too heavy	User is uncomfortable; cannot wear for an extended period of time	3.5	1. Fan is too big for system	1. reading through fan specifications 2. consumer research survey	1	1. consumer clinic	3	10.50						
	Battery is too heavy	User is uncomfortable; cannot wear for an extended period of time	5.0	1. Battery is too big for system	1. reading through battery specifications 2. consumer research survey	6	1. consumer clinic	3	90.00						
	Backpack is too heavy	User is uncomfortable; cannot wear for an extended period of time	5.0	1.Backpack is too big for system	1. reading through fan specifications 2. consumer research survey	3	1. consumer clinic	3	45.00						
	Weight is not well distributed on the users back/body	User is uncomfortable; cannot wear for an extended period of time	5.5	1. Backpack is worn incorrectly 2. Helmet center of gravity is not centered on users head	1. Dynamic analysis (FBD of forces put on body put design) 2. consumer research survey	4	1. consumer clinic	2	44.00						
Transports clean air from battery pack to headgear (Hose Configuration)	Not enough clean air reaches user	Does not provide clean air	9.0	1. Hose is too small	1. airflow analysis	6	1. testing, measure airflow over user's face 2. consumer clinic	4	216.00	Find a way to measure how much air is getting to the user	Peter 1/21/2021	will be measuring airflow through the hose with a hot wire anemometer			
	Hose has a crack or leak	Not enough airflow to user	9.0	1. Subjected to excessive motion which causes damage and wear	TBD	1	1. visual examination	1	9.00						
	Connections at each end are not secure	Ambient air seeps in at some point	8.5	1. Assembled incorrectly 2. connections lose their effectiveness over time	1. adhesive shear analysis	3	1. leak testing	5	127.50	FInd a way to secure connections without making them permanent	Jomil 1/21/2021	have bought hose clamps to secure housing			
System must be	The adhesives don't hold	wears down over time, ambient air seeps in	5.5	1. Lose effectiveness over time	1. will test multiple adhesives and bonds	5	1. leak testing	5	137.50	Make sure material does not allow air to come in	Becky 2/9/2021	have eliminated adhesives from our design.			

Product: True Barrier Face Respirator

Team: F62

Design Failure Mode and Effects Analysis

Prepared by: Jomil Aquipel

Date: 11/20/2020 (orig)

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
assembled to ensure no contamination (General, Hose)	Adhesives or coating contains toxic chemicals	user is exposed to unsafe contaminants	8.0	1. materials are not properly vetted, and unsafe materials are used	1. Choose adhesives/coatings deemed safe by FDA	2	1. check FDA regulations	1	16.00						
Fan can provide new, clean air (fan/battery/backpack)	Fan inlet is blocked	Not engouh airflow to the user	7.5	1. not enough access to ambient air 2. inlet is blocked by the positioning of the backpack	1. airflow analysis to determine inlet dimensions 2. Enusre inlet has access to ambient air	3	1. configuration's structural stability and position in backpack will be tested	3	67.50						
	Fan breaks	Not engouh airflow to the user	8.5	1. inadequate power supply 2. inlet is blocked 3. other components in battery pack do not let the fan function	1. Power required analysis 2. airflow analysis	2	1. life and durability will be tested	4	68.00						
Comfortable environment inside the mask (Head Configuration)	Sealed where not necessary (sealing method)	Inhibits auditory communication, user uncomfortable	4.0	1. seal surrounds too much of the users face	1. minimizing sealing	7	1. airflow testing to measure user's volume 2. consumer clinic	3	84.00						
	Temperature is too hot or cold	user uncomfortable, sweating, fogging up	4.0	1. seal traps warm air and leads to poor air circulation 2. Flowrate is too low and doesn't cool user 3. Flow rate is too high and impares auditory communication	1. airflow analysis	5	1. airflow testing to detemine which rate is comfortable	4	80.00						
Doesn't inhibit mobility (Fan/Battery/Backpack, Head & Hose conf.)	User's head cannot make full range of motion	inhibits visual communication, user uncomfortable, inhibits user's ability to function and do simple tasks	5.0	1. Hose restricts motion 2. Helmet is bulky and obtuse 3. Backpack restricts motion	1. minimizing profile of design 2. concumer research survey	4	1. consumer clinic	3	60.00						
Able to hear user speak and user can hear others	Helmet/headgear blocking user's ears	Inhibits auditory communication	4.5	1. users ears are covered	1. design not covering user's ears	0	1. visual examination	1	0.00						
	Seal is too tight that blocks sound	Inhibits auditory communication, user uncomfortable	4.5	1. seal traps the user's voice	1. minimizing amount of sealing	8	1. testing flow with seal 2. consumer clinic	8	288.00	Fing a way to amplify sounds from the inside of the mask	Julia 4/29/2021	knew that blocking sound was a problem for both open and sealed designs; will be purchasing a microphone			

Product: True Barrier Face Respirator

Team: F62

Design Failure Mode and Effects Analysis

Prepared by: Jomil Aquipel

Date: 11/20/2020 (orig)

												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
(Fan/Battery/Backpack & Head configuration, and hose configuration)	Fan is too loud	Inhibits auditory communication, user uncomfortable	4.5	1. Poor placement of fan/battery pack in relation to user's head	1. locate fan opposite user's mouth and far away	6	1. consumer clinic	2	54.00						
	fan is too close to the user's ears	Inhibits auditory communication, user uncomfortable	4.5	1. Poor placement of fan/battery pack in relation to user's head	1. locate fan opposite user's mouth and far away	2	1. consumer clinic	1	9.00						
	Air flow rate is too high	Inhibits auditory communication, user uncomfortable	5.0	1. Inadequate testing	1. keeping airflow away from user's ears	3	1. consumer clinic 2. testing will determine safe airflow	3	45.00						
Able to see user's visual communication cues (Head configuration)	Unable to see through the components in front of the user's face	inhibits visual communication	6.5	1. Fog 2. Glare	1. purchase clear visor 2. wide-range optics	1	1. consumer clinic	3	19.50						
Maintains appearance with wear (general)	Surfaces get damaged	wears down over time, is visually unappealing	5.5	1. Dropped on accident 2. Materials are fragile	1. Use more durable materials with what budget allows	4	1. exposure to UV 2. drop testing	4	88.00						
Sleek, appealing design (head configuration)	Helmet is ugly and bulky	is visually unappealing	5.5	1. Budget is insufficient for better aesthetic design	1. During design and testing, slim down prototype as much as possible	4	1. consumer clinic	3	66.00						
Maintains a barrier to keep out non-filter and ensure filtered air is delivered to the user	Shield/helmet cracks	inhibits visual communication,ambient air seeps in, visually unappealing	6.5	1. Hose gets caught on something and is pulled off 2. Dropped on accident	1. Properly fasten hose to headgear and user	1	1. visual examination	1	6.50						
	Sealing method not sufficient where necessary	Ambient air seeps in at some point, uncomfortable	7.0	1. Adhesive begins to degrade 2. Not properly assembled	1. Testing of sealant and airflow of helmet to assure sufficient sealing	7	1. speak with Dr. Mayer about testing methods	6	294.00	o-rings, hose clamps	Peter 4/29/2021	have designed an all-encompasing housing to mitigate risk of air intrusion.			
Doesn't inhibit mobility	User's head cannot make full range of motion	inhibits user's ability to function and perform simple tasks	5.5	1. Rigid/stiff hose 2. Hose too short 3. Hose too long 4. Hose is not secured properly	1. Testing of hose types for best flexibility and range of motion. 2. Properly fasten hose to headgear and user so it doesn't get in the way	5	1. consumer clinic	3	82.50						

Product: True Barrier Face Respirator

Design Failure Mode and Effects Analysis

Prepared by: Jomil Aquipel

Team: F62

Date: 11/20/2020 (orig)

												Action Results			
System / Function	**Potential Failure Mode**	**Potential Effects of the Failure Mode**	**Severity**	**Potential Causes of the Failure Mode**	**Current Preventative Activities**	**Occurence**	**Current Detection Activities**	**Detection**	**Priority**	**Recommended Action(s)**	**Responsibility & Target Completion Date**	**Actions Taken**	**Severity**	**Occurence**	**Criticality**
System must be assembled to ensure no contamination	The adhesives don't hold	ambient air seeps in	5.5	1. Not assembled correctly 2. Lose effectiveness over time	1. Have videos and written instructions on how to properly assemble 2. Reappy adhesives after a few months	4	1. create instructions 2. Testing bond strength and durability, as well as leak	5	110.00						
	Adhesives or coating contains toxic chemicals	user is exposed to unsafe contaminants	6.5	1. User inhales unsafe chemicals.	1. Choose adhesives/coatings deemed safe by FDA	2	1. check FDA regulations	1	13.00						

Appendix [N]: Design Hazard Checklist

Y	N	
■		1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
■		2. Can any part of the design undergo high accelerations/decelerations?
	■	3. Will the system have any large moving masses or large forces?
	■	4. Will the system produce a projectile?
	■	5. Would it be possible for the system to fall under gravity creating injury?
	■	6. Will a user be exposed to overhanging weights as part of the design?
■		7. Will the system have any sharp edges?
	■	8. Will any part of the electrical systems not be grounded?
	■	9. Will there be any large batteries or electrical voltage in the system above 40 V?
■		10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
	■	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
	■	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
	■	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
■		14. Can the system generate high levels of noise?
	■	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc.?
■		16. Is it possible for the system to be used in an unsafe manner?
■		17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, on the reverse side add:
(1) a complete description of the hazard,
(2) the corrective action(s) you plan to take to protect the user, and
(3) a date by which the planned actions will be completed.

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
The fan on the blower will be revolving with a high velocity.	Our plan is to either purchase a pre-concealed blower system or create a protective casing durable enough so that the fan blades are never exposed.	1/15/21	5/4/2021
The air flow may accelerate or decelerate dramatically depending on the battery and effectiveness of the blower.	Ideally, we will incorporate some sort of indicator to notify the wearer when the battery life is low (like in the 3M Versaflo) so that the air flow doesn't decrease or shut off completely while in use. Additionally, we plan to purchase batteries and blowers already tested and rated to last our target use time without malfunction.	1/15/21	5/4/2021
The system may have sharp edges around the bottom of the plastic shield, on the head piece, or the blower pack itself.	All sharp edges will be sufficiently covered with cushion material, rounded, or removed depending on the situation. We will assess the shield with numerous test users to verify there are no more exposed sharp edges.	1/15/21	5/4/2021
There will be a battery which will power the blower and enable it to retrieve the inlet air.	Our plan is to purchase off the self-batteries that are already tested and verified to avoid any issues with hazardous malfunction.	1/15/21	5/4/2021
The system can potentially generate significant noise from the fan and blower and the air flow being released into the shield.	To minimize the effect of any noise, the blower will be placed low on the user's back, far from the ears. Additionally, we will be using large enough tubing and nozzles to avoid constraining a steady, smooth flow of air from reaching the user's face. The air flow rate will also be high enough to keep a comfortable positive pressure, but not excessively high so that additional noise is created.	1/15/21	5/4/2021
The most hazardous way the shield may be misused would be by blocking the inlet or outlet air openings while the mask is on.	In order to minimize the chance of this happening, the blower inlet will be placed so that even when the user may be standing against a surface or seated, the opening is not blocked. There will also be very explicit user directions, explaining not to impede the outlet opening in any way	1/15/21	5/4/2021
There is potential for the HEPA filter to lose effectiveness over time.	We plan on including an indicator light to notify the wearer when it is necessary to replace the filter.	1/15/21	5/4/2021

Appendix [O]: Risk Assessment

designsafe Report

Application:	Closed Configuration	Analyst Name(s):	Jomil Aquipel, Julia Carlson, Peter Hunt, Becky Lu
Description:		Company:	
Product Identifier:		Facility Location:	
Assessment Type:	Detailed		
Limits:			
Sources:			
Risk Scoring System:	ANSI B11.0 (TR3) Two Factor		

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	tester first use / test	mechanical : drawing-in / trapping / entanglement Hose getting caught, something getting sucked into blower	Serious Likely	High	fixed enclosures / barriers: shorten hose length and secure hose to user's body	Serious Unlikely	Medium	TBD [2/25/2021] Julia Carlson
1-1-2	tester first use / test	mechanical : pinch point Putting headstraps into place, securing belt clips, screwing in filter	Minor Likely	Low		Minor		
1-1-3	tester first use / test	electrical / electronic : water / wet locations electronics get wet	Serious Unlikely	Medium	fixed enclosures / barriers, warning label(s): Will create waterproof housing and include labels to not get electronics wet	Serious Remote	Low	TBD [3/17/2021] Peter Hunt
1-1-4	tester first use / test	slips / trips / falls : instability improperly worn	Moderate Unlikely	Low		Moderate		
1-1-5	tester first use / test	slips / trips / falls : falling material / object battery pack falls	Moderate Likely	Medium	fixed enclosures / barriers: Housing will be durable and parts will be clamped down so they don't break apart.	Moderate Unlikely	Low	TBD [3/17/2021] Julia Carlson

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-6	tester first use / test	fire and explosions : hot surfaces battery overheating	Moderate Likely	Medium	warning label(s): Warn user that battery may become hot over time while in use.	Moderate Unlikely	Low	TBD [3/17/2021] Becky Lu
1-1-7	tester first use / test	fire and explosions : flammable liquid / vapor lithium battery	Catastrophic Remote	Low		Catastrophic		
1-1-8	tester first use / test	noise / vibration : interference with communications unable to hear user	Moderate Very Likely	High	use alternate methods: have the option of using a microphone and speaker system	Moderate Unlikely	Low	In-process Peter Hunt
1-1-9	tester first use / test	ventilation / confined space : confined space battey stops working	Serious Unlikely	Medium		Serious		
1-1-10	tester first use / test	ventilation / confined space : too much ventilation flowrate is too high	Minor Likely	Low		Minor		
1-1-11	tester first use / test	ventilation / confined space : loss of exhaust flowrate is too low	Moderate Likely	Medium	instruction manuals: Instruct user to select correct flowrate	Moderate Unlikely	Low	In-process Jomil Aquipel
1-1-12	tester first use / test	ventilation / confined space : lack of fresh air flowrate is too low or filter is not working	Serious Unlikely	Medium		Serious		
1-1-13	tester first use / test	ventilation / confined space : air contaminants filter is not working	Serious Unlikely	Medium		Serious		
1-1-14	tester first use / test	ventilation / confined space : airflow direction exhaust is blocked or flowrate is too low	Moderate Likely	Medium		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-15	tester first use / test	fluid / pressure : explosion / implosion lithium battery failure	Catastrophic Remote	Low		Catastrophic		
1-1-16	tester first use / test	fluid / pressure : low pressure air filter not installed correctly, gasket not working	Serious Unlikely	Medium		Serious Unlikely	Medium	TBD [2/25/2021] Julia Carlson
1-2-1	tester normal use	mechanical : drawing-in / trapping / entanglement Hose getting caught, something getting sucked into blower	Serious Likely	High	fixed enclosures / barriers: shorten hose length and secure hose to user's body	Serious		
1-2-2	tester normal use	mechanical : pinch point Putting headstraps into place, securing belt clips, screwing in filter	Minor Likely	Low		Minor		
1-2-3	tester normal use	electrical / electronic : water / wet locations electronics get wet	Serious Unlikely	Medium	fixed enclosures / barriers, warning label(s): Will create waterproof housing and include labels to not get electronics wet	Serious Remote	Low	TBD [3/17/2021] Peter Hunt
1-2-4	tester normal use	slips / trips / falls : impact to / with battery pack malfunctions, crack in shield	Serious Unlikely	Medium		Serious		
1-2-5	tester normal use	slips / trips / falls : falling material / object battery pack falls	Moderate Unlikely	Low	fixed enclosures / barriers: Housing will be durable and parts will be clamped down so they don't break apart.	Moderate Unlikely	Low	Julia Carlson
1-2-6	tester normal use	fire and explosions : hot surfaces battery overheating	Moderate Likely	Medium	warning label(s): Warn user that battery may become hot over time while in use.	Moderate Unlikely	Low	TBD [3/17/2021] Becky Lu

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-2-7	tester normal use	noise / vibration : interference with communications unable to hear user	Moderate Very Likely	High	use alternate methods: have the option of using a microphone and speaker system	Moderate Unlikely	Low	In-process Peter Hunt
1-2-8	tester normal use	ventilation / confined space : confined space battey stops working	Serious Unlikely	Medium		Serious		
1-2-9	tester normal use	ventilation / confined space : lack of fresh air filter is not working	Serious Unlikely	Medium		Serious		
1-2-10	tester normal use	ventilation / confined space : air contaminants filter is not working	Serious Unlikely	Medium		Serious		
1-2-11	tester normal use	ventilation / confined space : airflow direction exhaust is blocked	Moderate Unlikely	Low		Moderate		
1-2-12	tester normal use	fluid / pressure : low pressure air gasket not working	Serious Remote	Low		Serious		
1-3-1	tester trouble-shooting / problem solving	mechanical : pinch point fastening parts	Minor Likely	Low		Minor		
1-3-2	tester trouble-shooting / problem solving	electrical / electronic : energized equipment / live parts not turned off before fixing	Moderate Unlikely	Low		Moderate		
1-3-3	tester trouble-shooting / problem solving	electrical / electronic : improper wiring	Serious Likely	High	instruction manuals: Include clear instructions and diagrams of wiring	Serious Unlikely	Medium	Complete [2/11/2021] Jomil Aquipel

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-3-4	tester trouble-shooting / problem solving	electrical / electronic : unexpected start up / motion blower still connected to battery when fixing	Moderate Unlikely	Low		Moderate		
1-3-5	tester trouble-shooting / problem solving	fire and explosions : sparks	Serious Remote	Low		Serious		
1-3-6	tester trouble-shooting / problem solving	noise / vibration : product / equipment damage user error	Moderate Unlikely	Low		Moderate		
1-4-1	tester misuse	mechanical : drawing-in / trapping / entanglement unable to take mask off	Moderate Remote	Negligible		Moderate		
1-4-2	tester misuse	electrical / electronic : improper wiring	Serious Unlikely	Medium		Serious		
1-4-3	tester misuse	noise / vibration : product / equipment damage	Moderate Unlikely	Low		Moderate		
1-4-4	tester misuse	noise / vibration : interference with communications not wearing speaker/mic	Moderate Likely	Medium		Moderate		
1-4-5	tester misuse	ventilation / confined space : air contaminants filter not attached or improperly attached	Serious Unlikely	Medium		Serious		
2-1-1	adult first use / test	mechanical : drawing-in / trapping / entanglement Hose geting caught, something getting sucked into blower	Serious Likely	High	fixed enclosures / barriers: shorten hose length and secure hose to user's body	Serious Unlikely	Medium	TBD [2/25/2021] Julia Carlson

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-2	adult first use / test	mechanical : pinch point Putting headstraps into place, securing belt clips, screwing in filter	Minor Likely	Low		Minor		
2-1-3	adult first use / test	electrical / electronic : improper wiring blower to battery wiring	Serious Likely	High	instruction manuals: Include clear instructions and diagrams of wiring	Serious Remote	Low	Complete [2/11/2021] Jomil Aquipel
2-1-4	adult first use / test	electrical / electronic : water / wet locations electronics get wet	Serious Unlikely	Medium	fixed enclosures / barriers, warning label(s): Will create waterproof housing and include labels to not get electronics wet	Serious Remote	Low	TBD [3/17/2021] Peter Hunt
2-1-5	adult first use / test	slips / trips / falls : impact to / with battery pack malfunctions, crack in shield	Serious Unlikely	Medium		Serious		
2-1-6	adult first use / test	slips / trips / falls : instability improperly worn	Moderate Unlikely	Low		Moderate		
2-1-7	adult first use / test	slips / trips / falls : falling material / object battery pack falls	Moderate Likely	Medium	fixed enclosures / barriers: Housing will be durable and parts will be clamped down so they don't break apart.	Moderate Unlikely	Low	Julia Carlson
2-1-8	adult first use / test	ergonomics / human factors : excessive force / exertion breaks knob on voltage regulator	Moderate Unlikely	Low		Moderate		
2-1-9	adult first use / test	ergonomics / human factors : lifting / bending / twisting product is too heavy	Moderate Unlikely	Low		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-10	adult first use / test	fire and explosions : hot surfaces battery overheating	Moderate Likely	Medium	warning label(s): Warn user that battery may become hot over time while in use.	Moderate Unlikely	Low	TBD [3/17/2021] Becky Lu
2-1-11	adult first use / test	fire and explosions : flammable liquid / vapor lithium battery	Catastrophic Remote	Low		Catastrophic		
2-1-12	adult first use / test	noise / vibration : interference with communications unable to hear user	Moderate Very Likely	High	use alternate methods: have the option of using a microphone and speaker system	Moderate Unlikely	Low	In-process Peter Hunt
2-1-13	adult first use / test	ventilation / confined space : confined space battey stops working	Serious Unlikely	Medium		Serious		
2-1-14	adult first use / test	ventilation / confined space : too much ventilation flowrate is too high	Moderate Likely	Medium		Moderate		
2-1-15	adult first use / test	ventilation / confined space : loss of exhaust flowrate is too low	Moderate Likely	Medium	instruction manuals: Instruct user to select correct flowrate	Moderate Unlikely	Low	In-process Jomil Aquipel
2-1-16	adult first use / test	ventilation / confined space : lack of fresh air flowrate is too low or filter is not working	Serious Unlikely	Medium		Serious		
2-1-17	adult first use / test	ventilation / confined space : air contaminants filter is not working	Serious Unlikely	Medium		Serious		
2-1-18	adult first use / test	ventilation / confined space : airflow direction exhaust is blocked or flowrate is too low	Moderate Likely	Medium		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-19	adult first use / test	fluid / pressure : explosion / implosion lithium battery failure	Catastrophic Remote	Low		Catastrophic		
2-1-20	adult first use / test	fluid / pressure : low pressure air filter not installed correctly, gasket not working	Serious Unlikely	Medium		Serious		
2-2-1	adult normal use	mechanical : drawing-in / trapping / entanglement Hose geting caught, something getting sucked into blower	Serious Likely	High	fixed enclosures / barriers: shorten hose length and secure hose to user's body	Serious Unlikely	Medium	TBD [2/25/2021] Julia Carlson
2-2-2	adult normal use	mechanical : pinch point Putting headstraps into place, securing belt clips, screwing in filter	Minor Likely	Low		Minor		
2-2-3	adult normal use	electrical / electronic : water / wet locations electronics get wet	Serious Unlikely	Medium	fixed enclosures / barriers, warning label(s): Will create waterproof housing and include labels to not get electronics wet	Serious Remote	Low	TBD [3/17/2021] Peter Hunt
2-2-4	adult normal use	slips / trips / falls : impact to / with battery pack malfunctions, crack in shield	Serious Unlikely	Medium		Serious		
2-2-5	adult normal use	slips / trips / falls : instability improperly worn	Moderate Remote	Negligible		Moderate		
2-2-6	adult normal use	slips / trips / falls : falling material / object battery pack falls	Moderate Unlikely	Low	fixed enclosures / barriers: Housing will be durable and parts will be clamped down so they don't break apart.	Moderate Unlikely	Low	Julia Carlson

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-2-7	adult normal use	ergonomics / human factors : excessive force / exertion breaks knob on voltage regulator	Moderate Unlikely	Low		Moderate		
2-2-8	adult normal use	ergonomics / human factors : lifting / bending / twisting product is too heavy	Minor Remote	Negligible		Minor		
2-2-9	adult normal use	fire and explosions : hot surfaces battery overheating	Moderate Likely	Medium	warning label(s): Warn user that battery may become hot over time while in use.	Moderate Unlikely	Low	TBD [3/17/2021] Becky Lu
2-2-10	adult normal use	noise / vibration : interference with communications unable to hear user	Moderate Very Likely	High	use alternate methods: have the option of using a microphone and speaker system	Moderate Unlikely	Low	In-process Peter Hunt
2-2-11	adult normal use	ventilation / confined space : confined space battey stops working	Serious Unlikely	Medium		Serious		
2-2-12	adult normal use	ventilation / confined space : too much ventilation flowrate is too high	Moderate Unlikely	Low		Moderate		
2-2-13	adult normal use	ventilation / confined space : loss of exhaust flowrate is too low	Moderate Unlikely	Low	instruction manuals: Instruct user to select correct flowrate	Moderate Unlikely	Low	In-process Jomil Aquipel
2-2-14	adult normal use	ventilation / confined space : lack of fresh air flowrate is too low or filter is not working	Serious Unlikely	Medium		Serious		
2-2-15	adult normal use	ventilation / confined space : air contaminants filter is not working	Serious Unlikely	Medium		Serious		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-2-16	adult normal use	ventilation / confined space : airflow direction exhaust is blocked or flowrate is too low	Moderate Unlikely	Low		Moderate		
2-2-17	adult normal use	fluid / pressure : low pressure air filter not installed correctly, gasket not working	Serious Remote	Low		Serious		
2-3-1	adult trouble-shooting / problem solving	mechanical : pinch point fastening parts	Minor Likely	Low		Minor		
2-3-2	adult trouble-shooting / problem solving	electrical / electronic : energized equipment / live parts not turned off before fixing	Moderate Unlikely	Low		Moderate		
2-3-3	adult trouble-shooting / problem solving	electrical / electronic : improper wiring	Serious Unlikely	Medium		Serious		
2-3-4	adult trouble-shooting / problem solving	electrical / electronic : unexpected start up / motion blower still connected to battery when fixing	Moderate Unlikely	Low		Moderate		
2-3-5	adult trouble-shooting / problem solving	fire and explosions : sparks	Serious Remote	Low		Serious		
2-3-6	adult trouble-shooting / problem solving	noise / vibration : product / equipment damage user error	Moderate Unlikely	Low		Moderate		
2-4-1	adult misuse	mechanical : drawing-in / trapping / entanglement unable to take mask off	Moderate Remote	Negligible		Moderate		

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-4-2	adult misuse	mechanical : product instability wearing improperly	Moderate Unlikely	Low		Moderate		
2-4-3	adult misuse	electrical / electronic : improper wiring	Serious Likely	High	instruction manuals: Include clear instructions and diagrams of wiring	Serious Remote	Low	Complete [2/11/2021] Jomil Aquipel
2-4-4	adult misuse	noise / vibration : product / equipment damage	Moderate Unlikely	Low		Moderate		
2-4-5	adult misuse	noise / vibration : interference with communications not wearing speaker/mic	Moderate Likely	Medium		Moderate		
2-4-6	adult misuse	ventilation / confined space : lack of fresh air improper flowrate	Moderate Unlikely	Low		Moderate		
2-4-7	adult misuse	ventilation / confined space : air contaminants filter not attached or improperly attached	Serious Unlikely	Medium		Serious		
3-1-1	passer-by / non-user walk near	mechanical : drawing-in / trapping / entanglement	Minor Likely	Low		Minor		
3-1-2	passer-by / non-user walk near	ventilation / confined space : air contaminants user's air not filtered	Serious Very Likely	High	warning label(s): assure that the user knows that they may pass on COVID-19 to those around them due to their outlet air not being filtered if they are infected	Serious Unlikely	Medium	In-process Becky Lu

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-1-3	passer-by / non-user walk near	fluid / pressure : vacuum	Moderate Unlikely	Low		Moderate		
3-2-1	passer-by / non-user misuse	mechanical : drawing-in / trapping / entanglement	Minor Likely	Low		Minor		
3-2-2	passer-by / non-user misuse	slips / trips / falls : falling material / object user doesn't secure device	Moderate Likely	Medium		Moderate		
3-2-3	passer-by / non-user misuse	noise / vibration : noise / sound levels > 80 dBA flowrate too high	Moderate Unlikely	Low		Moderate		
3-2-4	passer-by / non-user misuse	fluid / pressure : explosion / implosion	Catastrophic Remote	Low		Catastrophic		
3-3-1	passer-by / non-user observe / watch	fluid / pressure : explosion / implosion lithium battery failure	Catastrophic Remote	Low		Catastrophic		

Appendix [P]: User Manual

True Barrier Face Shield User Manual

As our design aims for the user to assemble the product, the steps needed to put together the complete face shield are listed below.

Step 1: Place the 2-½' O-ring down on the blower inlet, in the groove in the top housing piece.

Step 2: Place the blower in the housing and screw it to the housing using the three 10-24 x 3/8’ screws. Be sure to hold the blower tight to the 3D printed housing so that there is a tight seal between blower and housing.

Step 3: Place the 1-5/8’ O-ring around the threads on the filter.

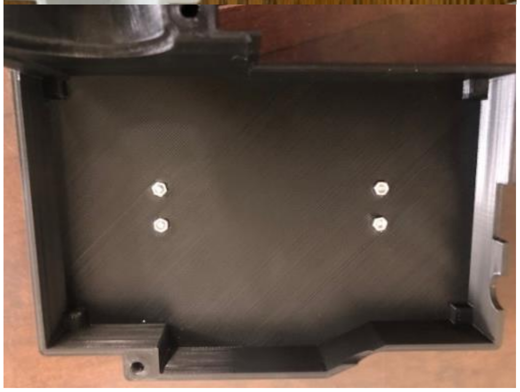
Step 4: Attach the filter to the connector by screwing it into the top housing. When the filter is screwed into place, make sure that the O-ring is firmly seated between the filter and the housing. If the O-ring is not placed correctly, there is a risk that polluted air may get sucked in by the blower.

Step 5: On the bottom housing, align the belt clip holes to the holes in the housing and insert 1 1/8 x 1/4” through the hole and the belt clips.

Step 6: Flip the housing insert washer through bolt.

Step 7: Tighten nut into the bolt and make sure it stays in place.

Step 8: Repeat steps 5-7 for remaining 3 bolts, washers, and nuts to fully attach belt clips to the housing.



Next, we need to attach the battery to the blower to complete the housing assembly.

Step 9: Connect the cables of the blower into the male DC 2.1mm x 5.5 mm wire by clipping them together with the XT60 connectors.

Step 10: Put the filter, battery, and blower all inside our housing. Place the XT60 connectors in the cut out (as seen in the bottom housing seen on right) with the cabling through the small groove in the housing wall. Tighten housing together again using 10-24 screws where there are holes.

The rest of the steps below are to put the rest of the face mask together. Make sure the first two subsystems are competed before attaching everything else.

Step 11: Attach the hose to the nozzle located on the housing. Tighten down with hose clamp, making sure not to overtighten.

Step 12: Place the 3D printed connector between the hose and the shield. Attach the hose to the connector and tighten down with hose clamp, making sure not to overtighten.

Step 13: Connect the DC battery cable into the outlet located on the battery.

Once you have completed all these steps, you will now have a fully functioning PAPR.

Instructions for Properly Wearing Respirator

The safety provided by a PAPR can be negated if it is not properly put on. In order to protect the user and provide the highest level of safety, please follow the instructions to put on.

Step 1: Turn system on. When pressed down, the dash signifies power is on; the circle signifies power off.

Step 2: Confirm that the filter is firmly secure by twisting clockwise until finger tight.

Step 3: Attach battery pack to secure location (e.g. belt, backpack, bag straps, etc.).

Step 4: Verify that flow is being provided to the mask by placing your hand at the mask inlet and feeling the air flow.

Step 5: Put mask on face. Unclip the mask strap buckles, place mask on head, reclip strap buckles, and then tighten straps to create full seal around face.

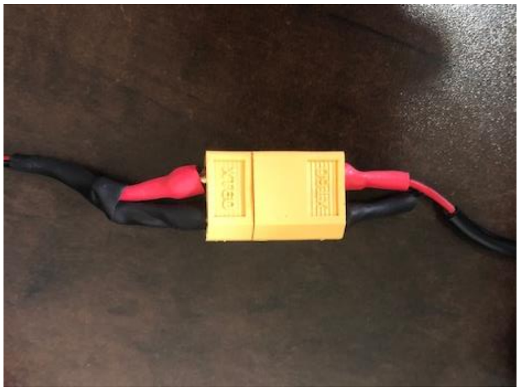
Charging the Battery

Whenever possible, the battery should be fully charged which is indicated by all five green lights being lit up on the battery. The higher the battery level, the greater the flowrate, leading to optimal operation of the device. Therefore, whenever the respirator is initially applied or removed the battery level should be checked. If the battery level is showing 2 lights or below, the battery should be charged. Any time after the device is done being used it is recommended that the battery is also charged.

To charge battery, disconnect cable next to the power switch that is coming from the housing. Turn on the battery by pressing the switch to the dash position. Next plug in the external battery charging cable into this inlet and plug the charge into a wall outlet. The green lights should turn red when the battery is being charged and will turn back to green when it has reached full capacity. Once fully charged, turn off the battery and reconnect the cable from the housing to the battery port.

Disconnecting Cabling

The cabling is quite sensitive and can be broken if not properly handled.



Inside the housing, there are several cables that need to be handled with some caution. The cables attached to the blower are loosely attached to the blower itself, but they are very tightly attached to the XT-60 adaptor. These cables should not be pulled with excessive force on the blower side. This may lead to a broken connection which will require a new blower. Whenever the cable is being disconnected to charge, this needs to be done with minimal force. Additionally, if the XT-60 cable ever has to be disconnected for wire troubleshooting, this should be done by only apply force to sperate the yellow connector, and never on the connection between the cable and blower.

Troubleshooting

In the event that the battery is powered, and the blower does not turn, check that the battery is charged. If it is, the cabling could be the source of the problem. Ensure that the connections between the cables and the blower are still intact.

In the event that there is no, or diminished, airflow being provided to the mask, check for an occlusion or leakage in the system. For an occlusion, remove the source of the blockage. Identify leakage by running hands along the device to feel for escaping air. When the location of the leak is found, seal or replace the defective part. If no leakage or occlusion is found, it may be time to change the filter.

Maintenance and Replacing Parts

Keeping the device sanitary is a vital to ensure the integrity of the device. After use, wipe down the mask and surfaces with antibacterial wipes. Be sure to store the device out of sunlight, as the UV rays can damage the 3D printed PLA.

There was no provided data about the life of the filter that we purchased for our design; however, based on available literature and our use of the filter, it will remain effective until there are visible signs of blockage. For context, we have used the same filter for about 50 hours of testing, and the efficiency has remained constant at 99.99%.

Adhesives are not used in our design to make it easy to replace and swap parts as necessary. To replace a part, please refer to the Intended Bill of Materials (Appendix G) for a full list of parts and their vendors.

Appendix [Q]: Design Verification Plan & Report

DVP&R - Design Verification Plan (& Report)												
Project:	Laminar Flow Face Shield		Sponsor:	Dr. Chen					Edit Date:			
LM										**TEST RESULTS**		
Test #	Specification	Test Description	Measurements	Acceptance Criteria	Required Facilities/Equipment	Parts Needed	Responsibility	TIMING		Numerical Results	Pass/Fail	Notes on Testing
								Start date	Finish date			
1	1	User Experience Survey: We are going to be surveying (0-10 scale) volunteers on different specifications while they are wearing the mask in various locations.	Comfort	85% approval	Prefer indoor since respirator will be used in the classroom, but want outdoor use as well. No equipment neccessary.	Volunteers, and working full system prototype (need at least one prototype for this)	Julia	5/1/21	5/20/21	Average rating of 9.2	Pass	Most user's felt pretty comfortable wearing device
	4		User's voice, team member can hear the user from 20 feet away	>70% approval raF8:F19ting (average score of 7 or greater)			Becky			Average rating of 7.2	Pass	Voice muffling was minimal when wearing the mask and blower did not obstruct sound. Still may implement a microphone speaker system in order to imporve this result.
	5		User's visibility, user can see well 20 feet away	>85% approval rating (average score of 8.5 or greater)			Jomil			Average rating of 6.8	Fail	This was primarily due to the curvature of the snorkel mask. Next iteration will use a smoother mask surface or may need a custom manufactured mask.
	6		User's hearing, user can hear 20 feet away	>70% approval rating (average score of 7 or greater)			Peter			Average rating of 7.6	Pass	Hearing with the device was almost on par with hearing without any obstruction. Blower supplied very minial background noise.
	7		Anti-fogging	Does not fog, passing with an average score of >2 (0 is no fogging at all)			Becky			Average rating of 0	Pass	No user expereinced any fogging
	14		Aesthetics	70% Approval, (average score of 7 or greater)			Jomil			Average rating of 6.2	Fail	The mask itself was the largest issue with aestethic approval rating. This should be altered in the next iteratoin by utilizing a different mask with a sleeker design.
2	3a	Flow Rate Verification: We are going to test flow rate our device exhibits over time and confirm it meets CDC guidelines. To measure the flow rate, we will either use a hot wire anemometer inside our full system.	Flowrate into respirator (from duct)	>115 L/min OR 4.06 cfm	Facilities: none Equipment: hot wire anemometer, in-line flowmeter & power source	Full System prototype	Peter	5/1/21	5/20/21	Average flowrate of 11.99 cfm or 339.6 L/min	Pass	Value generally decreased over time, but only slightly. May be due to disturbances throughout the testing with senstive measurment device or actual drop in flowrate as the batteyr voltage decreases.
	3b											
3	2	Battery Life Characterization: We will run the face shield at full capacity to confirm the battery runs and the devices works for at least 6 hours. Voltage cannot drops below 10 V for all 6 hours.	Battery Life	6 Hours	Facilities: none Equipment: none	filter, silicone gasket, connector, screws, blower, hose, and battery	Becky	4/22/21	5/4/21	Battery has been tested with full system connected for 6 hours. Battery life only went down to 4/5 lights. It went down from 12.29 V to 11.1 V.	Pass	Battery lasts a lot longer than 6 hours.
4	8	General Use: We will time volunteers to see how long it takes for the to perform tasks that are necessary when using the face shield.	Time taken to completely sanitize mask	120 seconds	Facilities: none Equipment: stopwatch	Volunteers, and working full system prototype (need at least one prototype for this)	Julia	5/1/21	5/19/21	The average time to sanitize the mask was 112.83 seconds.	Pass	On average, we were able to meet our target time.
	9		Application/ Removal Time	Less than 60 seconds			Julia	5/1/21	5/20/21	Average time to put on: 78.7 sec Average time to take off: 17.5 sec	Fail- Application time Pass- Removal time	Takes much longer to put on small of back than it is to put on at the hip. Putting the device on a belt on back makes the device feel much lighter and easier to move around.
5	12	Particle Counter Test: we will run the system in a typical classroom like environment with the the Cal Poly particle counter inside the face shield, against mannequin head to measure change in number of particles in the face shield.	Safety	99.9% of particles in the mabient air are filtered by the device	Equipment: mannequinn head, particle counter	Full System prototype	Jomil	4/15/21	5/12/21	Our data is now showing a filtration rate of 99.93%	Pass	After sufficient sealant and tweaked testing procedure the device met saftey rating.
6	2	Battery Sizing Test: We will see how much voltage and current is needed to run the fan at CDC guidelines speed and buy a battery that can last 6 hours at those conditions	Battery Sizing	6000 mAh	Equipment: Voltage supply, voltmeter	blower	Peter	2/18/21	3/9/21	We found a 12V 6000 mAh battery that we are going to use for our design.	N/A	No notes

Appendix [R]: Test Procedures & Results

Test Name: Battery Sizing Test

Purpose: To determine the current draw of our system to identify a proper battery for our system.

Scope: The function of this test is to choose a battery for our system based on the performance of the blower at different voltages.

Equipment:

- Anemometer
- GW DC Power Supply (Model Number: GPS-3030D)
- Pair of alligator clips
- Constructed Prototype
- Test Duct

Hazards: The current and voltage we start with can be too high for the system, which can blow up the battery. Beware of letting the leads touch, as this could short the system the power supply.

PPE Requirements: None

Facility: Room with standard 120 V outlets.

Procedure:

1. Plug in power supply and fix leads to the power supply.
2. Attach alligator clips to the blower in the prototype.
3. Turn on power supply ad set the voltage to 6V on the power supply. Turn off any current limit.
4. Vary the voltage and by intervals of 0.5V until you reach 12V. Record the voltage, temperature, current and velocity at each voltage.
5. Measure the cross-sectional are of the test duct. Use this number to convert the velocity into ta volumetric flow.
6. Calculate the mAh required for 3 hours of battery life at each of the different voltages.

Test Date(s): 2/25/2021

Performed By: Peter Hunt

Battery Sizing Test Results:

Voltage [V]	Current [A]	Measured Flow Velocity [ft/min]	Corrected Flow Velocity [ft/min]	Flowrate [cfm]	Flowrate [L/min]
6	0.123	79	73.9	3.2	89.5
6.5	0.149	91	85.1	3.6	103.1
7	0.176	101	94.5	4.0	114.4
7.5	0.211	111	103.9	4.4	125.8
8	0.232	117	109.5	4.7	132.6
8.5	0.245	129	120.7	5.2	146.2
9	0.271	138	129.1	5.5	156.3
9.5	0.292	142	132.9	5.7	160.9
10	0.312	150	140.4	6.0	169.9
10.5	0.336	158	147.8	6.3	179.0
11	0.358	162	151.6	6.5	183.5
11.5	0.374	168	157.2	6.7	190.3
12	0.407	174	162.8	7.0	197.1

Test Results: A 12 V battery will be sufficient to power our system. To obtain a safety factor of at least two, a 6000 mAh battery will be sufficient for our system.

Test Name: Flow Rate Verification Test

Purpose: To determine that our system provides enough air to the user over the life of the battery according to CDC guidelines.

Scope: Our respirator is designed for teachers, and we expect the ventilation rate to be close to normal. According to CDC guidelines, a closed-shield respirator must blow at 4 cfm, or 84.95 L/min. To provide a factor of safety of 3, our design will aim to provide a flow rate of at least 389 L/min for the specification of a 3 hour battery life.

Equipment:

- Hot wire anemometer (TSI 8345 Velocicalc)
- Constructed Prototype
- Constructed test duct for the hot wire anemometer probe to measure airflow through the hose

Safety Concerns:

Hazards	Response
Malfunction of the anemometer or battery while test is running	Turn off all system devices and check all connections

PPE Requirements: Safety Googles

Facility: Bonderson 2nd Floor

Procedure:

1. Make sure the hot wire anemometer is calibrated. Measure the inside diameter of the test duct to find the cross-sectional area of the duct.
2. Connect the test duct to the end of the hose.
3. Insert the hot wire anemometer inside the test duct hole and turn on device.
4. Take velocity readings in ft/s every 2 minutes for 1 hour. Convert to cfm by multiplying by the cross-sectional area of the duct and record the results on a table.

Test Date(s): 5/1/2021

Performed by: Julia Carlson

Flow Rate Verification Test Results:

Time [min]	Velocity [ft/min]	Flowrate [cfm]
0	1380	12.33180
2	1380	12.33180
4	1390	12.42116
6	1390	12.42116
8	1360	12.15308
10	1370	12.24244
12	1360	12.15308
14	1310	11.70627
16	1340	11.97435
18	1340	11.97435
20	1320	11.79563
22	1350	12.06372
24	1340	11.97435
26	1370	12.24244
28	1360	12.15308
30	1350	12.06372
32	1350	12.06372
34	1330	11.88499
36	1350	12.06372
38	1340	11.97435
40	1350	12.06372
42	1340	11.97435
44	1330	11.88499
46	1340	11.97435
48	1340	11.97435
50	1340	11.97435
52	1310	11.70627
54	1300	11.61691
56	1300	11.61691
58	1290	11.52755
60	1290	11.52755

Test Results: Average 11.99 cfm which is greater than the CDC recommended 4.06 cfm multiplied by a safety factor of two. - Pass

Test Name: Battery Life Characterization

Purpose: The purpose of this test is to find the reliability of the battery. We want to make sure it lasts our promised time of at least 6 hours, which is the equivalent of 2 labs in one day.

Scope: This test is to test the life of the battery while running.

Equipment:

- Whole closed face shield setup
- Dummy head
- Timer
- Multimeter
- Hot wire anemometer
- Propeller anemometer

Hazards:

Safety Issue	Response
Possibility of battery overheating and sparks if the system gets wet.	Monitor battery and know how to power off system.
When cutting the mannequin head fixture, be careful while cutting material due to possible sharp edges	Cut on a sturdy surface.

PPE Requirements: There is no need for PPE

Facility: The test can occur in any room

Procedure:

1. Put dummy head inside the facemask. This is important because we want all losses possible to be in the system while it is being tested. Ensure battery is fully charged.
2. Turn on the system.
3. Measure the voltage of the battery every 10 minutes for 6 hours.

Test Date(s): 5/4/21

Performed By: Jomil Aquipel

Test Results: The battery voltage was able to stay above 9 volts and stay on for 6 hours. - Pass

Battery Life Characterization Results:

Time [min]	Voltage [V]
0	12.29
10	12.21
20	12.14
30	12.09
40	12.04
50	12.02
60	12.00
70	11.97
80	11.93
90	11.89
100	11.84
110	11.80
120	11.77
130	11.730
140	11.670
150	11.620
160	11.570
170	11.530
180	11.500
190	11.460
200	11.420
210	11.400
220	11.420
230	11.380
240	11.350
250	11.320
260	11.290
270	11.250
280	11.220
290	11.190
300	11.170
310	11.140
320	11.110
330	11.080
340	11.060
350	11.040
360	11.010

Test Name: General Use Survey: User Experience

Description: The purpose of this test is to verify the user experience of our device meets our required standards, with regard to comfort, communication, visibility, and aesthetics.

Equipment:

- Complete Prototype
- Volunteer user
- Google survey for comfort, communication, and aesthetics evaluation
- 20-foot marker
- Data sheet for results

Safety Concerns:

Hazards	Response
Insufficient cleaning/disinfecting time between users'	Ensure the cleaning procedures are strictly followed and at least 24 hours between each new user
Inability to effectively hear user while device is on and running	Ensure user is aware of how to remove device in case of emergency or malfunction
Improper usage by volunteer	Train all new users on the usage of the device and make sure a team member is always watching and with the user at all times while the device is on and running

PPE Requirements: Safety goggles, face covering, cleaning supplies for the device

Facility: User's home

Procedure:

1. Explain procedure and device to the volunteer, send link to google survey.
2. Have volunteer put on the device, confirm secure connections, etc.
3. Have volunteer stand 20 feet away from team member, while team member reads aloud set phrases.
4. Repeat process with volunteer reading aloud set phrases.
5. Have volunteer and team member fill out first two questions on survey on a 0-10 scale of communication effectiveness. Additionally, team member rates visibility of volunteer's face.
6. After at least 15-20 minutes with volunteer wearing device, have volunteer fill out remainder of the survey: scale 0-10 comfort, scale 0-10 visibility, scale 0-10 fogging, scale 0-10 personal aesthetic appeal.
7. Any additional comments from volunteer, submitted with the survey.
8. Remove device from the volunteer.
9. Thoroughly clean device and allow for at least 1 full day between each additional user.

Test Date(s): 5/1-5/20

Performed By: Team F62

Survey Questions:	**Responses:**
Have you ever worn or used a similar PPE device?	Y/N
How well could you hear the team members words?	0-10
How well did you feel the team member could hear you?	0-10
How well could you see your surroundings through the mask?	0-10
How comfortable was the mask on your face and battery pack on your body?	0-10
Did you notice any fogging inside the mask?	0-10
How would you rate the aesthetic appeal of the device?	0-10
Any additional comments about your experience while wearing the device?	-

Test Results:

Passing criteria:

- Comfort >85% approval rating, average of all volunteer scores
- Aesthetics >70% approval rating, average of all volunteer scores
- Fogging, pass/fail if score is above 2=fail
- Communication and visibility approval rating determined from volunteer averages

Communication >70% approval, visibility >85% approval

	Question on Survey:	Results (average rating):
Volunteer user questions:	1. How well could you hear the team members words from 20 feet away? (0-Not at all, 10-Very well)	9.2 (pass)
	2. How well did you feel the team member could hear you? (0-Not at all, 10-Very well)	5 (N/A)
	3. How well could you see your surroundings through the mask? (0-Not at all, 10-Very well)	6.8 (fail)
	4. How comfortable was the mask on your face and battery pack on your body? (0-very uncomfortable, 10-very comfortable)	7.6 (pass)
	5. Did you notice any fogging inside the mask? (0-none, 10- a lot)	0 (pass)
	6. How would you rate the aesthetic appeal of the device? (0-very unappealing, 10-very appealing)	6.2 (fail)
Team member question:	7. How well could you hear the user from 20 feet away, speaking at a normal volume? (0-not at all, 10-very well)	7.2 (pass)

Test Name: Quantifying Sanitization Time of Face Shield

Purpose: The purpose of this test is to validate that the face shield is capable of being completely sanitized in 2 minutes or less by wiping down the interior and exterior of the face shield with antibacterial wipes.

Equipment:

- Structural prototype
- Stopwatch
- Antibacterial wipes

Hazards:

Safety Concerns	Responses
Possibility of tester pinching themselves while clipping or unclipping straps.	Insert straps with caution, paying close attention to where fingers are.
Possibility of skin irritation from antibacterial wipes.	If irritation occurs, please immediately stop and wash irritated area thoroughly.

Facility: Can be performed anywhere.

Procedure:

1.) Obtain equipment.
2.) Make sure that the stopwatch is reset to zero.
3.) Take out one antibacterial wipe from the container.
4.) Start the stopwatch and begin to thoroughly wipe interior surfaces of face shield.
5.) Once interior surfaces have been wiped down, thoroughly wipe all exterior surfaces of face shield, hose, and battery pack.
6.) Once all exterior surfaces have been wiped down, stop the stopwatch and record the time in the "Sanitization Time [s]" column in the table below.
7.) Reset the stopwatch.
8.) Wait 20 minutes for the face shield to completely dry.
9.) Repeat steps 1 through 8 three more times, for a total of four runs.

Test Date(s): 5/16/21

Tested by: Team F62

Results:

Run #	Sanitization Time [s]
1	152
2	117
3	145
4	115
5	67
6	81

The average time it took users to sanitize the device took longer than expected. This does not meet the set criteria. – Fail

Test Name: Quantifying Application and Removal Time of Face Shield

Purpose: The purpose of this test is to validate that the face shield is capable of being put on and taken off in 45 seconds or less by unclipping the straps, putting the face shield in place, and reclipping the straps in place without needing a mirror.

Equipment:

- Structural prototype
- Stopwatch

Hazards:

Safety Concerns	**Responses**
Possibility of tester pinching themselves while clipping or unclipping straps.	Insert straps with caution, paying close attention to keeping hair away from inserts.
Possibility of tester's hair becoming tangle or pulled by straps while putting on and taking off shield.	Put on the mask with caution, paying close attention to hair placement.

PPE Requirements: Face covering for stopwatch operator

Facility: Can be performed anywhere

Procedure:

1. Obtain stopwatch and two willing volunteers (one will operate stopwatch while other will perform test).
2. Participants will be 6 feet apart. Make sure that the stopwatch is reset to zero. Make sure that the straps of the face shield are properly clipped into place.
3. Person operating stopwatch will countdown from three and on "go" will start the stopwatch. Person performing test will begin to put on face shield.
4. When face shield is properly put on, person operating stopwatch will immediately stop the stopwatch and record the time into "Application Time" column in table below.
5. Reset stopwatch.
6. Person operating stopwatch will countdown from three and on "go" will start the stopwatch. Person performing test will begin to take off face shield.
7. When face shield is completely taken off, person operating stopwatch will immediately stop the stopwatch and record the time into "Removal Time" column in table below.
8. Reset stopwatch.
9. Repeat steps 1 through 8 three more times, for a total of 4 runs.

Test Date(s): 5/5

Performed by: Becky Lu

Application and Removal Time Test Results:

Run #	Application Time [s]	Removal Time [s]
1	96	4
2	167	60
3	43	10
4	35	9
5	62	12
6	69	10
7	162	13
8	73	7

The average application time was slightly higher than the criteria, but did not pass. - Fail
The average removal time was able to meet the criteria. - Pass

Test Name: Characterization of Particulate Distribution Count

Description: The purpose of this test is to determine the safety of our design by finding the count of viral sized particulates (0.06-0.14 micrometers) that the user is exposed to when wearing the face shield.

Check:
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7293495/#:~:text=Droplets%20in%20the%20range%20of,et%20al.%2C%201996

Equipment:

- Particle Counter
- Complete Prototype

Hazards:

Safety Issue	Response
Possibility of battery overheating and sparks if the system gets wet.	Monitor battery and know how to power off system.
When cutting the mannequin head fixture, be careful while cutting material due to possible sharp edges	Cut on a sturdy surface.

PPE Requirements: Safety goggles, face covering, following COVID protocols

Facility: Tester's home indoors

Procedure:

1. Measure amount of viral sized particulates in ambient air.
2. Secure particle counter tube at the end of the respirator hose.
3. Measure starting particles coming out of the respirator hose.
4. Turn on the system and leave it running for an hour and 15 minutes, take particle measurement every 3 minutes for the duration of the experiment.
5. After every measurement inside the hose, take a measurement of ambient air.
6. Compare particulate count of ambient air to the end of the hose at the end of the test.

Results:

Test Situation	Particle Count
Average End of Hose	371
Average Ambient Air	412294
Percent Filtered	99.91%
Pass/Fail	Pass

The test passed due to 99.91% of particles being filtered.

Test Date(s): 4/15/21-5/15/21

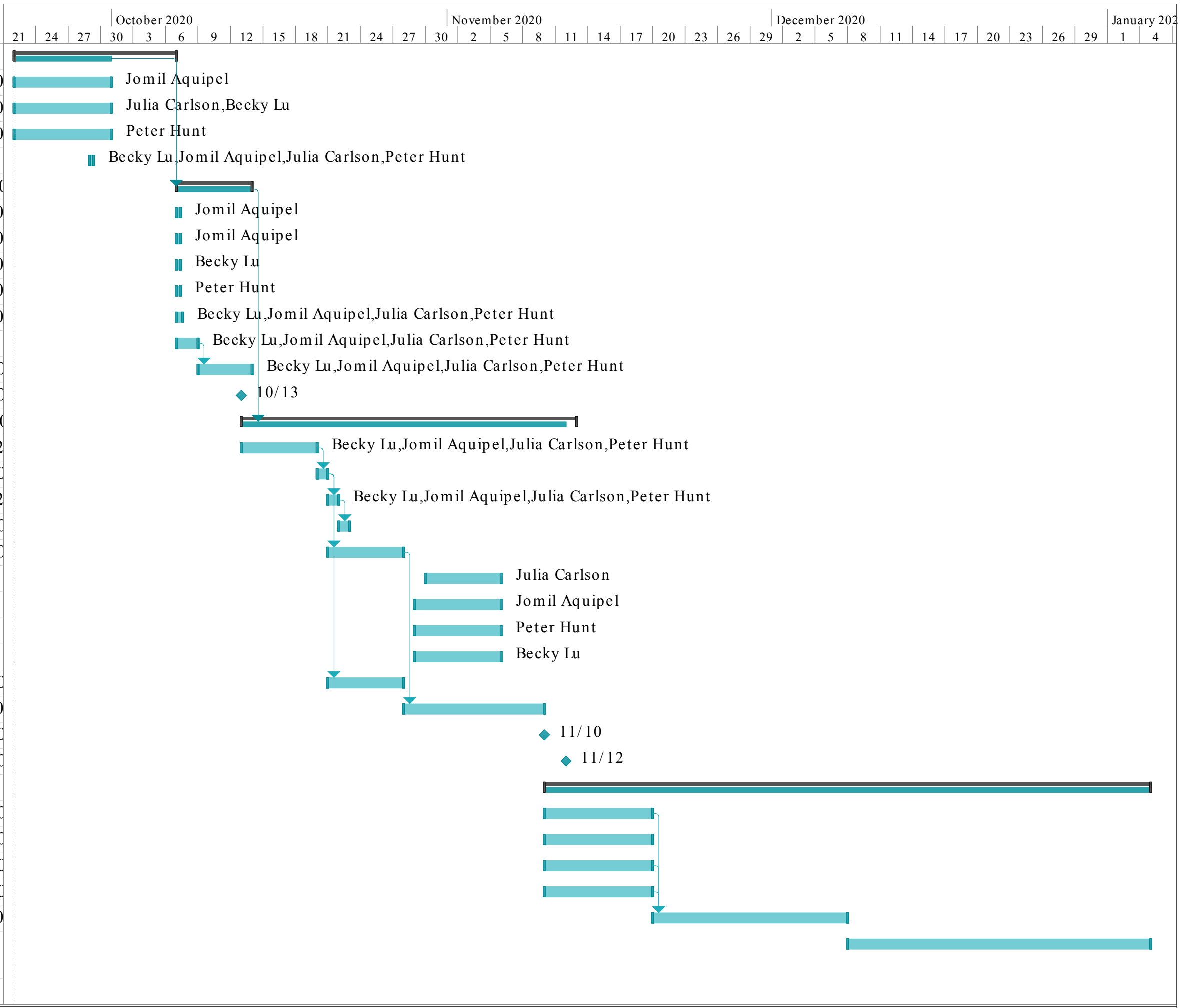
Test Results: Pass

Performed By: Team F62

Appendix [S]: Gantt Charts

Fall 2020:

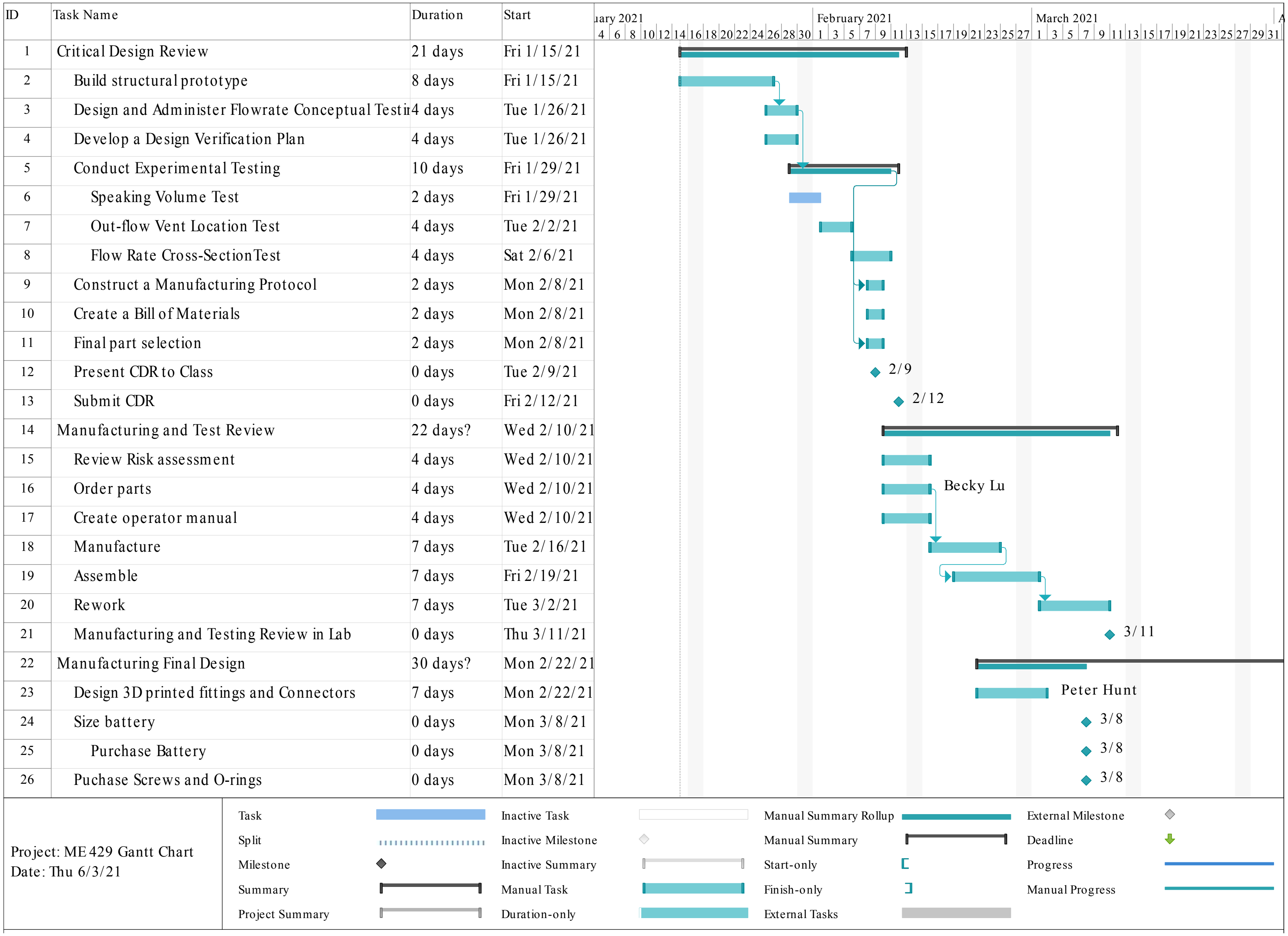
ID	Task Name	Duration	Start	Finish
1		11 days	Tue 9/22/20	Tue 10/6/20
2	Complete Customer Interviews	7 days	Tue 9/22/20	Wed 9/30/20
3	Research Patents and Existing Products	7 days	Tue 9/22/20	Wed 9/30/20
4	Review Academic Journals and Studies	7 days	Tue 9/22/20	Wed 9/30/20
5	Hold Informational Meeting	1 hr	Tue 9/29/20	Tue 9/29/20
6	Scope of Work	5 days?	Wed 10/7/2	Tue 10/13/2
7	Sketch Boundary Diagram	1 hr	Wed 10/7/20	Wed 10/7/20
8	Create customer wants/needs table	1 hr	Wed 10/7/20	Wed 10/7/20
9	Create specifications table	1 hr	Wed 10/7/20	Wed 10/7/20
10	Modify Gantt Chart/Project Timeline	1 hr	Wed 10/7/20	Wed 10/7/20
11	Create QFD House of Study	5 hrs	Wed 10/7/20	Wed 10/7/20
12	Draft of Scope of Work	2 days	Wed 10/7/20	Thu 10/8/20
13	Revise Scope of Work	3 days	Fri 10/9/20	Tue 10/13/2
14	Deliver Scope of Work	0 days	Tue 10/13/2	Tue 10/13/2
15	Preliminary Design Review	23 days?	Tue 10/13/2	Thu 11/12/2
16	Brainstorm ideas and create Pugh Matrici	5 days	Tue 10/13/2	Mon 10/19/2
17	Evaluate key components of design	1 day	Tue 10/20/2	Tue 10/20/2
18	Create a Morphological Matrix	1 day	Wed 10/21/2	Wed 10/21/2
19	Evaluate Morphological Matrix to make W	1 day	Thu 10/22/2	Thu 10/22/2
20	Create sophisticated system models	5 days	Wed 10/21/2	Tue 10/27/2
21	Description of the ideation process	5 days	Fri 10/30/20	Thu 11/5/20
22	Description of the final design selection pr	6 days	Thu 10/29/2	Thu 11/5/20
23	Description of the final design itself + CAD	6 days	Thu 10/29/2	Thu 11/5/20
24	Preliminary analysis and current risks	6 days	Thu 10/29/2	Thu 11/5/20
25	Develop CAD models for the main functio	5 days	Wed 10/21/2	Tue 10/27/2
26	Finish writing PDR	9 days	Wed 10/28/2	Mon 11/9/20
27	Present PDR to Class	0 days	Tue 11/10/2	Tue 11/10/2
28	Submit PDR	0 days	Thu 11/12/2	Thu 11/12/2
29	Interim Design Review	40 days	Tue 11/10/2	Mon 1/4/21
30	Conduct FMEA	8 days	Tue 11/10/2	Thu 11/19/2
31	Review Safety	8 days	Tue 11/10/2	Thu 11/19/2
32	Design for Manufacturability	8 days	Tue 11/10/2	Thu 11/19/2
33	Review Cost Analysis	8 days	Tue 11/10/2	Thu 11/19/2
34	Complete Design Analysis	12 days	Fri 11/20/20	Mon 12/7/20
35	Begin ideation process for structural prototype	20 days	Tue 12/8/20	Mon 1/4/21
36				



Project: ME 428 Gantt Chart
Date: Thu 6/3/21

Task	▬	Project Summary	┌─┐	Manual Task	▬	Start-only	[	Deadline	⇩
Split	┄	Inactive Task	▭	Duration-only	▬	Finish-only	]	Progress	─
Milestone	◆	Inactive Milestone	◇	Manual Summary Rollup	▬	External Tasks	▬	Manual Progress	─
Summary	┌─┐	Inactive Summary	┌─┐	Manual Summary	┌─┐	External Milestone	◆		

Winter 2021:

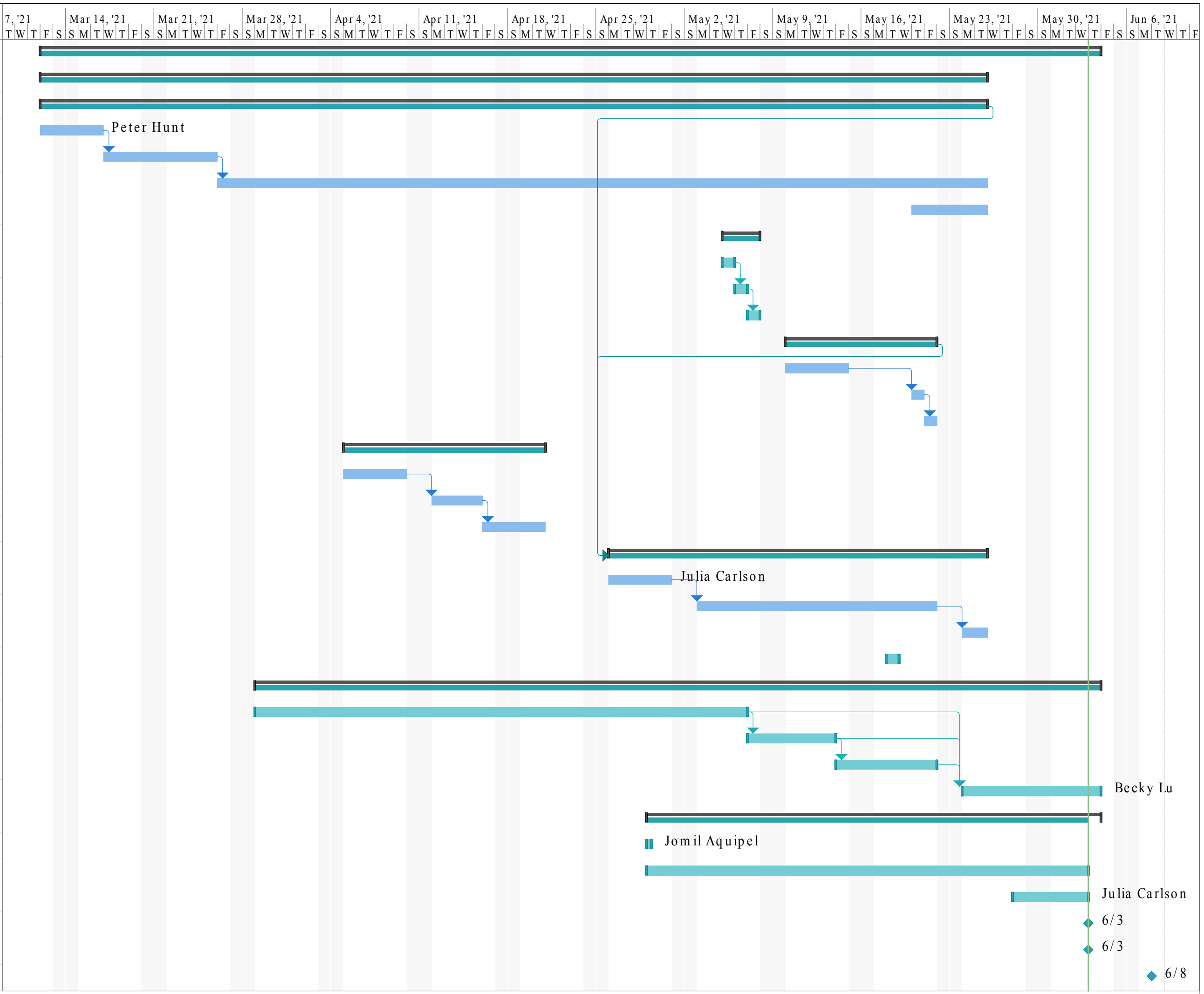


ID	Task Name	Duration	Start
1	Critical Design Review	21 days	Fri 1/15/21
2	Build structural prototype	8 days	Fri 1/15/21
3	Design and Administer Flowrate Conceptual Testir	4 days	Tue 1/26/21
4	Develop a Design Verification Plan	4 days	Tue 1/26/21
5	Conduct Experimental Testing	10 days	Fri 1/29/21
6	Speaking Volume Test	2 days	Fri 1/29/21
7	Out-flow Vent Location Test	4 days	Tue 2/2/21
8	Flow Rate Cross-Section Test	4 days	Sat 2/6/21
9	Construct a Manufacturing Protocol	2 days	Mon 2/8/21
10	Create a Bill of Materials	2 days	Mon 2/8/21
11	Final part selection	2 days	Mon 2/8/21
12	Present CDR to Class	0 days	Tue 2/9/21
13	Submit CDR	0 days	Fri 2/12/21
14	Manufacturing and Test Review	22 days?	Wed 2/10/21
15	Review Risk assessment	4 days	Wed 2/10/21
16	Order parts	4 days	Wed 2/10/21
17	Create operator manual	4 days	Wed 2/10/21
18	Manufacture	7 days	Tue 2/16/21
19	Assemble	7 days	Fri 2/19/21
20	Rework	7 days	Tue 3/2/21
21	Manufacturing and Testing Review in Lab	0 days	Thu 3/11/21
22	Manufacturing Final Design	30 days?	Mon 2/22/21
23	Design 3D printed fittings and Connectors	7 days	Mon 2/22/21
24	Size battery	0 days	Mon 3/8/21
25	Purchase Battery	0 days	Mon 3/8/21
26	Puchase Screws and O-rings	0 days	Mon 3/8/21

Project: ME 429 Gantt Chart
Date: Thu 6/3/21

Spring 2021:

ID	Task Name	Duration	Start	Finish
1	Expo	60 days	Fri 3/12/21	Thu 6/3/21
2	Testing	53 days	Fri 3/12/21	Tue 5/25/21
3	Particle Counter Testing	53 days	Fri 3/12/21	Tue 5/25/21
4	Construct fixture	3 days	Fri 3/12/21	Tue 3/16/21
5	Obtain Particle Counter	7 days	Wed 3/17/21	Thu 3/25/21
6	Conduct Test	43 days	Fri 3/26/21	Tue 5/25/21
7	Evaluate Results	4 days	Thu 5/20/21	Tue 5/25/21
8	Filter Testing	3 days	Wed 5/5/21	Fri 5/7/21
9	Construct Fixture	1 day	Wed 5/5/21	Wed 5/5/21
10	Complete Testing	1 day	Thu 5/6/21	Thu 5/6/21
11	Determine if filter is working	1 day	Fri 5/7/21	Fri 5/7/21
12	Flow Rate Verification	10 days	Mon 5/10/21	Fri 5/21/21
13	Procure adequate measurement dev	5 days	Mon 5/10/21	Fri 5/14/21
14	Conduct Test	1 day	Thu 5/20/21	Thu 5/20/21
15	Evaluate Results	1 day	Fri 5/21/21	Fri 5/21/21
16	Battery Life Characterization	12 days	Mon 4/5/21	Tue 4/20/21
17	Procure a multimeter/voltmeter	5 days	Mon 4/5/21	Fri 4/9/21
18	Conduct Test	4 days	Mon 4/12/21	Thu 4/15/21
19	Evaluate Results	3 days	Fri 4/16/21	Tue 4/20/21
20	General Use Survey and Time to Clean	22 days	Mon 4/26/21	Tue 5/25/21
21	Create a google survey link	5 days	Mon 4/26/21	Fri 4/30/21
22	Conduct Test	15 days	Mon 5/3/21	Fri 5/21/21
23	Evaluate Results	2 days	Mon 5/24/21	Tue 5/25/21
24	DVP&R Sign-Off	1 day	Tue 5/18/21	Tue 5/18/21
25	Write FDR report	49 days	Mon 3/29/21	Thu 6/3/21
26	Write Manufacturing Chapter	29 days	Mon 3/29/21	Thu 5/6/21
27	Write User Manual	5 days	Fri 5/7/21	Thu 5/13/21
28	Write Design Verification Chapter	6 days	Fri 5/14/21	Fri 5/21/21
29	Format and Editting	9 days	Mon 5/24/21	Thu 6/3/21
30	Project Webpage and Video	26 days	Thu 4/29/21	Thu 6/3/21
31	Create Website Expo Account	1 hr	Thu 4/29/21	Thu 4/29/21
32	Build Webpage	25 days	Thu 4/29/21	Wed 6/2/21
33	Project Video	4 days	Fri 5/28/21	Wed 6/2/21
34	Submit FDR to sponsor	0 days	Thu 6/3/21	Thu 6/3/21
35	Send email to Dr. Chen	0 days	Thu 6/3/21	Thu 6/3/21
36	Hand-off Prototype to Dr. Chen	0 days	Tue 6/8/21	Tue 6/8/21



Project: ME 430 Gantt Chart
Date: Thu 6/3/21

Task	▬	Project Summary	┌─┐	Manual Task	▬	Start-only	[	Deadline	⬇
Split	┄	Inactive Task	▭	Duration-only	▬	Finish-only	]	Progress	─
Milestone	◆	Inactive Milestone	◇	Manual Summary Rollup	─	External Tasks	▬	Manual Progress	─
Summary	┌─┐	Inactive Summary	┌─┐	Manual Summary	┌─┐	External Milestone	◆		