Jet Propulsion Laboratory
California Institute of Technology

# JPL Designed Powered Air-Purifying Respirator (PAPR)

As of May 28, 2020

## Executive Summary

In order to help provide Personal Protective Equipment (PPE) for the Coronavirus pandemic, a team at NASA's Jet Propulsion Laboratory (JPL) has created and tested a 3D printable Powered Air-Purifying Respirator (PAPR) device with custom filters and Commercial Off-The-Shelf (COTS) components. Utilizing a Wildhorn Outfitters® Full Face Snorkel Mask and other COTS equipment, the JPL design is available for use by motivated creators in an Open Source forum readily accessible by anyone wishing to produce the device. Some testing has been performed by JPL and others to verify that it meets the design requirements identified in **Public Health Title 42, Code of Federal Regulations, Part 84**, but it lacks any NIOSH or other medical institution approval. The device is intended to provide a last line of defense when certified PAPRs are not commercially available.


The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

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# Introduction

**In order to help provide Personal Protective Equipment (PPE) for the Coronavirus pandemic, a team at NASA's Jet Propulsion Laboratory (JPL) has created and tested a 3D printable Powered Air-Purifying Respirator (PAPR) device with custom filters and Commercial Off-The-Shelf (COTS) components. This device is not certified by NIOSH or any medical institution but is intended to provide a last line of defense when certified PAPRs are not commercially available. (See Disclaimer Section below).** The JPL PAPR system was designed to the requirements of **Public Health Title 42, Code of Federal Regulations (CFR), Part 84**, to the extent possible. Limited testing was performed to verify that the performance of the device would meet or exceed the requirements set forth in the 42 CFR, Part 84 and the results of the tests are included herein. Any tests that have not been completed at JPL, or may have been performed at an alternate venue are also identified. This entire package along with the downloadable 3D print files can be found via Open Source at:

https://github.com/nasa-jpl/COVID-19-PAPR

**This set of design data, bill of materials, assembly instructions, test results and operator instructions are released to Open Source with the hope that any companies and/or individuals who have access to a 3D printer, and want to help can print or create this device for those that need it.** We purposefully did not use materials in the normal medical supply chain so as not to negatively impact the availability of materials to commercially viable and certified PAPR suppliers. There is much left to be done and to be improved upon for this initial JPL PAPR design. Our expectations are that other motivated creators can use this design as a starting point and modify and improve the design going forward.

**JPL also wants to acknowledge and thank our partner in this endeavor, Wildhorn Outfitters®, whose Seaview 180 V2 mask was the inspiration for this PAPR design.** Wildhorn's motivation and sense of civic duty, led them to an investigation of using their snorkel product as a medical respirator. This in turn inspired JPL to extend this concept to a working PAPR design. Wildorn Outfitters supplied the JPL team with snorkel masks for the prototype designs and worked closely with us as the design progressed to this state. The reader can follow-up with Wildhorn Outfitters® COVID-19 efforts at the link below:

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https://www.wildhornoutfitters.com/pages/fullfacemaskcovid19-info


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# JPL PAPR Design Overview

*Figure 1: Test Engineer Shannon Berger with JPL Designed PAPR Unit*

A PAPR (Powered Air-Purifying Respirator) uses a blower to provide positive pressure to push air through a filter, and provides air to the user's face. This allows the user to breathe more naturally, while receiving constant airflow to the face. It maintains user comfort, even while working in warm environments. PAPRs enable the user to enter a contaminated ambient air, and provides protection from pollutants or pathogens by filtering the hazard.

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Advantages of PAPR:

- PAPR has a higher assigned protection factor (APF) than fitted face pieces, such as N95.
- The PAPR shields the eyes, nose & mouth from coming in contact with harmful particulates in the air. Thus helping prevent the user of PAPR from contracting COVID-19

NIOSH published interim standards, which developed a new PAPR100 Class: PAPR100-N. This is created to be more in alignment with health care provider needs and environment. More information about NIOSH interim standards can be found References 4 and 5.

The JPL PAPR design, presented in this document, is intended to meet NIOSH 42 CFR 84 definition and requirements for Tight-Fitted PAPR100-N. The "N" designation indicates it is not for use against oil-based aerosols.

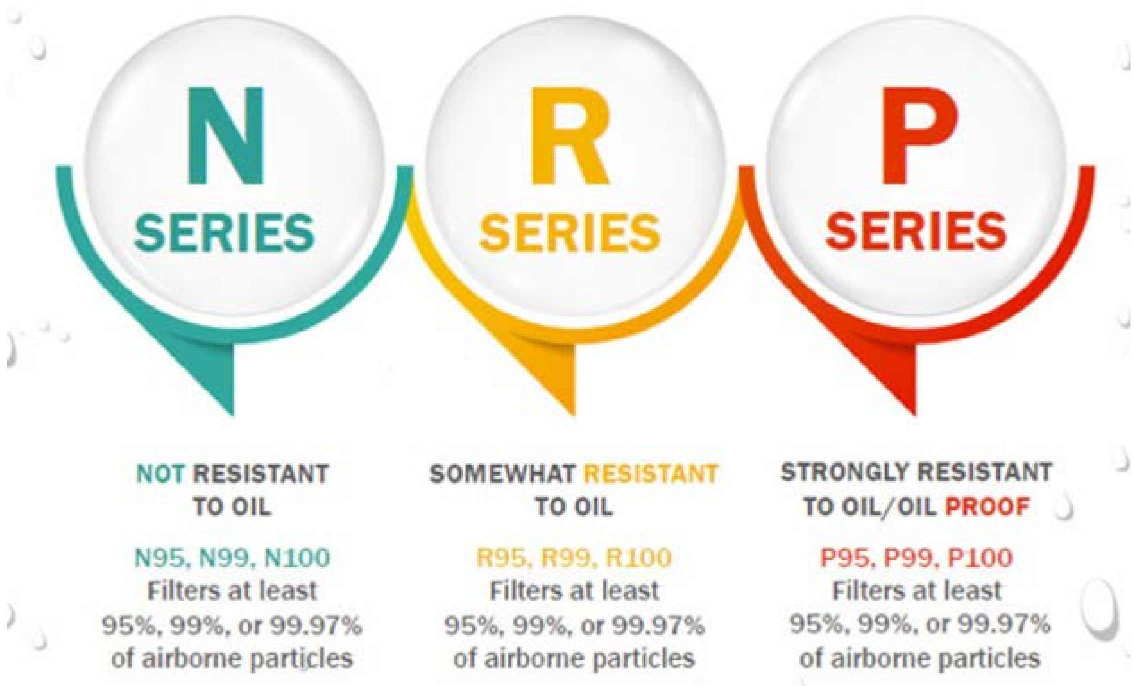


*Figure 2: NIOSH lettering designation for Personal Protective Equipment (PPE).*

The NIOSH interim standards also established new testing guidelines, to approve PAPR100's for use. Previous NIOSH requirements for PAPRs encompassed construction use cases. The new PAPR100-N classification creates a new Test

Matrix to gain NIOSH approval, outlined in Table 11 below. Since NIOSH provides certification for manufacturers, not designs, this design is not NIOSH approved. However, JPL pursued meeting the Test Matrix, to ensure if a manufacturer were to pick up this design to provide to Healthcare Professionals, all requirements are met. JPL also intended for this to be able to be built at home. All components selected are Commercial Off-The-Shelf (COTS), specifically selected to not impact the current medical supply chain.


*Figure 3: Fully assembled, functional PAPR100-N unit*

# Tools and Equipment

The following list of Tools and Equipment are required to enable assembly of the JPL designed PAPR system. The assembly requires a moderate amount of experience, particularly in the area of electronics assembly, however, the skills necessary are well within those of a home hobbyist.

- Phillips and flat head screwdriver
- Cardboard or cutting surface
- Silver sharpie (nice-to-have, not required)
- Black sharpie (nice-to-have, not required)
- Exacto Knife or equivalent
- Scissors or razor
- Wire stripper
- Soldering iron & solder
- Shrink wrap
- Heat gun
- Hot glue gun
- greenworks Lithium Ion Battery Charger
- T6 torx screwdriver
- Hammer
- Laptop to Download Arduino Software
- 15180115-1, Filter Tool 1, 3D Printed
- 15180116-1, Filter Tool 2, 3D Printed
- 15180117-1, Filter Tool 3, 3D Printed
- 15180118-1, Template, Filter Seal, Round, 3D Printed
- 15180118-2, Template, Filter Seal, Rectangular, 3D Printed

# Materials Required

The JPL PAPR team has generated a Bill-of Materials (BOM) for each of the two separate PAPR configurations. This detailed BOM can be found here https://github.com/nasa-jpl/COVID-19-PAPR. The PAPR System top assembly part number is 15180125 with the -1 version signifying the Globe Tools Blower version, and the -2 version signifying the ebmpapst Blower Motor version. These two different versions are functionally the same but slight design changes are included to manage the differences in the blower motor designs. **The individual shopping lists are included as separate tabs in BOM spreadsheet, link above.** The JPL PAPR BOM structure is shown below in a graphical representation for clarification. This illustrates the two different top level configurations and the lower level subassemblies that feed the top level.

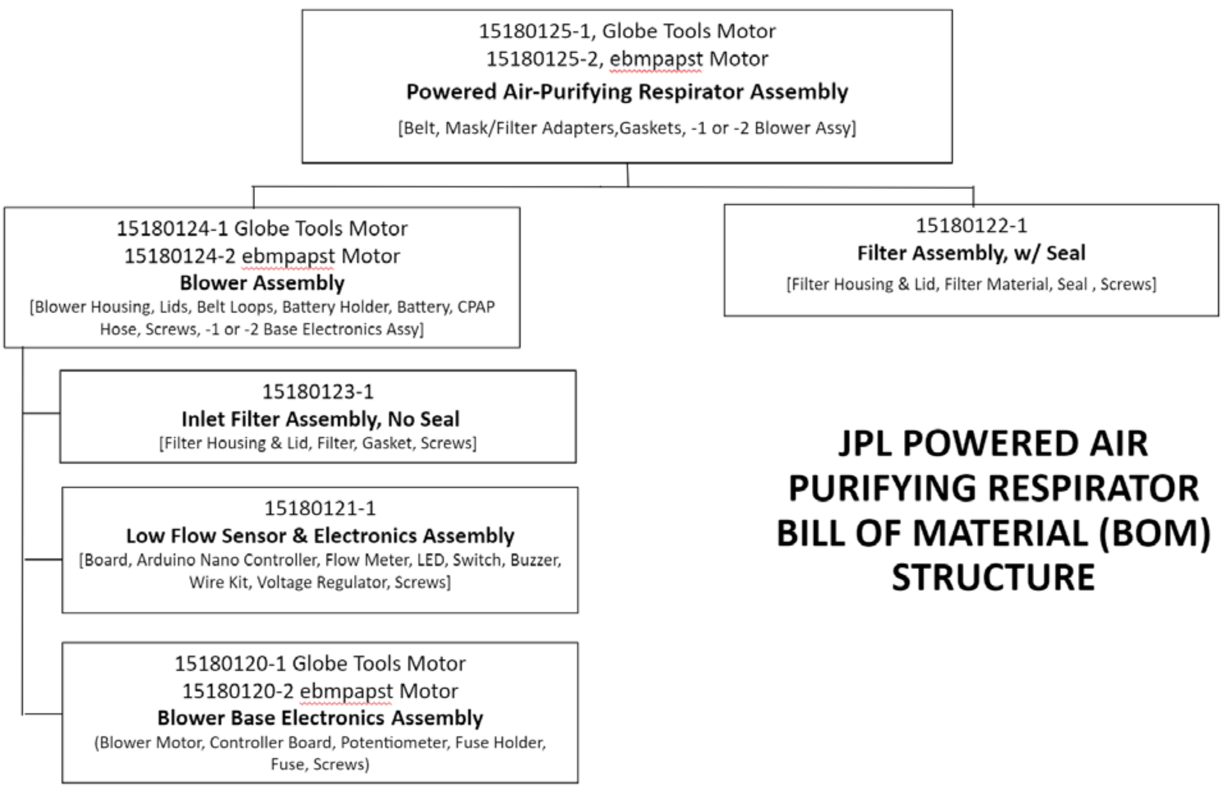


*Figure 4: Bill of Materials Structure*

The potential user/manufacturer can find further description of the differences between the blower motors in Appendix B - COTS Component Detailed Information, which may guide the user to an informed decision on which PAPR configuration to pursue. Once this is determined, the user may proceed with the purchase and build of the appropriate components and 3D parts based on the configuration selected.

A top level BOM is shown below for reference as an example. Please see the link above for the detailed BOM which also includes the lower level BOMs. The detailed BOMs include links to the supplier websites and individual components as well as some representative pricing information. Note that these prices are representative only and will be subject to future market fluctuations.

| | QTY | | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|---|
| | -1 | -2 | | | | | |
| **105108125 Powered Air Purifying Respirator Assembly** | 1 | 1 | 1 | Seaview 180 V2 | Snorkel Mask | | Wildhorn Outfitters |
| | 1 | 1 | 2 | P09 | Tactical Belt | | Amazon / Fairwin |
| | | 1 | 3 | 15180124-2 | Blower Assembly | ABS | JPL Assembly |
| | 1 | | 4 | 15180124-1 | Blower Assembly | ABS | JPL Assembly |
| | 2 | 2 | 5 | 15180119-1 | Gasket, Round, Filter Adapter | Multipurpose Neoprene Foam Strip | JPL Part |
| | 1 | 1 | 6 | 15180122-1 | Filter Assembly | ABS | JPL Assembly |
| | 1 | 1 | 7 | 15180109-1 | Hose Adapter | ABS | 3D Printed Component |
| | 1 | 1 | 8 | 15180112-1 | SeaView 180 V2 Snorkel Mask Side Adapter | ABS | 3D Printed Component |

*Table 1: Top Level PAPR System BOM Example*

The top level BOM above is intended to guide the user during the assembly activities later in this document. In this example, the JPL PAPR Assembly comes in two styles, 105190125-1 and 1510825-2. The difference is simply the utilization of Globe Tools blower vs ebmpapst blower. Functionally, these assemblies are equivalent. Several of the PAPR subassemblies have multiple configurations similar to the top assembly. The user is reminded to pay attention to what configuration (-1 or -2) is being built and assembled.

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# 3D Printed Components and Fabrication

Although the JPL PAPR design uses COTS parts, JPL designed 3D printed parts to package and support these COTS items so the system can perform the intended function. 3D printing enables the home user to download and fabricate these parts independently. The build files are provided through the Github link [https://github.com/nasa-jpl/COVID-19-PAPR] via Open Source.

Overall there are 11 individual 3D printed parts for the -1 PAPR Assembly (7 for the Blower & 4 for the Mask Adapter/Filter Assembly) and 13 individual 3D printed parts for the -2 PAPR Assembly (9 for the Blower and 4 for the Mask Adapter/Filter Assembly). A typical build layout for the Blower Assembly is shown in the photo below.

*Figure 5: Example Build Layout for the -2 PAPR Assembly. Does not include all pieces.*

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As anyone with 3D printing experience knows, there are build parameters and other considerations for printing 3D parts. The detailed print strategies are provided in Appendix A. These include part orientation and support & fill strategies. These strategies can be important, especially for those parts that are subject to PAPR air flow to the user, so as to avoid leaving behind particulate and unwanted fibers that might be unhealthy. Please refer to these strategies and implement them as needed.

Regarding 3D printable materials, JPL utilized Acrylonitrile Butadiene Styrene (ABS) material for the 3D printed components as the material of choice for the following reasons:

- ABS is a common material available to most, if not all, 3D printers.
- ABS has a melting temperature range that holds up to the thermal operating conditions.
- ABS structural properties were more enticing than other common 3D printer materials such as PLA or PETG.

It is worth noting that other common 3D printer materials could suffice for the material of choice for the PAPR build as long as the yield strength and melting temperature range of the selected material(s) is/are similar to that of ABS. Selecting a material that has a lower yield strength reduces the structural integrity, which suggests that the PAPR could fail under lower loads. Also, selecting a material with a lower melting temperature than ABS could lead to warped/distorted parts from operating temperature conditions / the environment in which the PAPR is used/stored.

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# Commercial Off-The-Shelf Components and Potential Sources

There are many Commercial Off-the-Shelf Components (COTS) that are utilized in the JPL PAPR assembly. In order to minimize impact to the medical supply chain, JPL had several discussions with some of the manufacturers of the key components (blower motors, flow sensors, hose, etc) to ensure that the JPL PAPR supply chain would avoid impact to the medical industry. Also, JPL inquired about supply and could these manufacturers meet a higher demand for these parts, if warranted. In all instances, the PAPR team received a positive response from these manufacturers. JPL appreciated their willingness to support this design effort.

As defined earlier, the detailed BOM, which is contained here https://github.com/nasa-jpl/COVID-19-PAPR, has links and pointers for the user to hone in on the needed parts for this build. We have also provided some information within this document that may support the user for planning and education purposes. Appendix B, Commercial Off-the-shelf Component Detailed Information, contains some of the information that the PAPR team learned in the design and development process. This information is provided here to assist the potential user in their own development process. It is recommended that the user review some of this information in determining which PAPR configuration would work best for the intended application.

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# Assembly Instructions

The following sections describe the assembly instructions for each of the JPL subassemblies, assemblies and COTS components. To aid the user, the following suggestions are provided as a guide, but they do not need to be followed precisely or in the order that is suggested.

## Prerequisites to Assembly

Prior to starting assembly, all of the 3D Printed parts should have been printed and available. These can be separated into their respective subassemblies as defined by the BOM.

In addition, all COTS parts should have been purchased and available. Many of the small miscellaneous parts can be purchased locally at hardware or automotive parts stores. The key components will require on-line purchase at the links provided in the BOM [which can be found here: https://github.com/nasa-jpl/COVID-19-PAPR] and may take anywhere from a day or two to be delivered, or up to a week, depending on the product. The key parts to order first are the Sensirion Flow Meter (Item 34) and the selected blower/motor assembly, either the Globe Tools blower and motor assembly (Items 50-52, purchased as a kit) or the ebmpapst blower and motor controller assembly (Items 47-49). Once all of the parts are acquired, the assembly can begin and the operations will flow smoothly.

## Assembly Operation Tips and Suggested Sequence

The following tips and suggested assembly sequence are provided as a means to simplify and and provide some organization for assembly.

Tips

- Ensure you know which assembly you are building, the Globe Tools (greenworks) blower (-1) or the ebmpapst blower (-2). They have slightly different components and build instructions.
    - Within the BOM assembly spreadsheet, there are separate tabs for shopping lists for the different assemblies.

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- Review each assembly BOM and lay out required parts at the outset of assembly. Assigning item numbers to the physical parts is optional.
- Gather the necessary tools for the specific assembly and ensure all tools and equipment are available.
- Consider printing a hardcopy of the assembly and subassembly instructions to allow easy reference.
- Build the Blower Assembly (PN 15180125-1 or -2) from the inside out, starting with the electronic assemblies. Once the electronics are operational, the mechanical assembly of these components can commence.
    - Note: The two electronic assemblies are the most demanding of this assembly operation and require the most skill and the most time

Suggested Assembly Sequence

1. Start by building the units common to both the -1 and -2 PAPR Assemblies
    - Filter Assembly (PN 15180122-1)
    - Inlet Filter Assembly (PN 15180123-1)
    - Low Flow Sensor and Electronics Assembly (PN 15180121-1)

2. Build the Blower assemblies depending on the -1 or -2 PAPR configuration as shown below:
    - Globe Tools Blower Assembly (PN 15180124-1) **- STARTS ON PAGE 32**
        - Globe Tools Blower Base Electronics Assembly (15180120-1)
    - ebmpapst Blower Assembly (PN 15180124-2) - **STARTS ON PAGE 48**
        - ebmpapst Blower Base Electronics Assembly (15180120-2)

3. Build the PAPR Top Assembly (PN 15180125-1 or -2) depending on the PAPR Configuration consisting of:
    - Filter Assembly (PN 15180122-1)
    - Blower Assembly (PN 151580124-1 **or** 15180124-2)

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# Filter Assembly (JPL PN 10580122-1)

| | QTY<br>-1 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180122 Filter Assembly** | 6 | 11 | 90065A110 | Screw, C-Sink, Phillips | 18-8 CRES, #4-1/2 in long | Mcmastercarr |
| | 1 | 29 | 93375K404 | Seal Material, Filter | Multipurpose Neoprene Foam Strip | Mcmastercarr |
| | 1 | 30 | 15180119-2 | Seal, Rectangular, Filter Adapter | Multipurpose Neoprene Foam Strip | JPL Part |
| | 1 | 26 | 53291 Style Q | HEPA Filter | HEPA Cloth Vacuum Bag | Kenmore |
| | 1 | 31 | 15180110-1 | Helmet Filter Base (Sealed 3m) | ABS | 3D Printed Component |
| | 1 | 32 | 15180111-1 | Helmet Filter Cover (Sealed 3m) | ABS | 3D Printed Component |

*Table 2:* 10580122-1 Bill of Materials (BOM)

Both versions of the assembly use the same Filter Assembly.

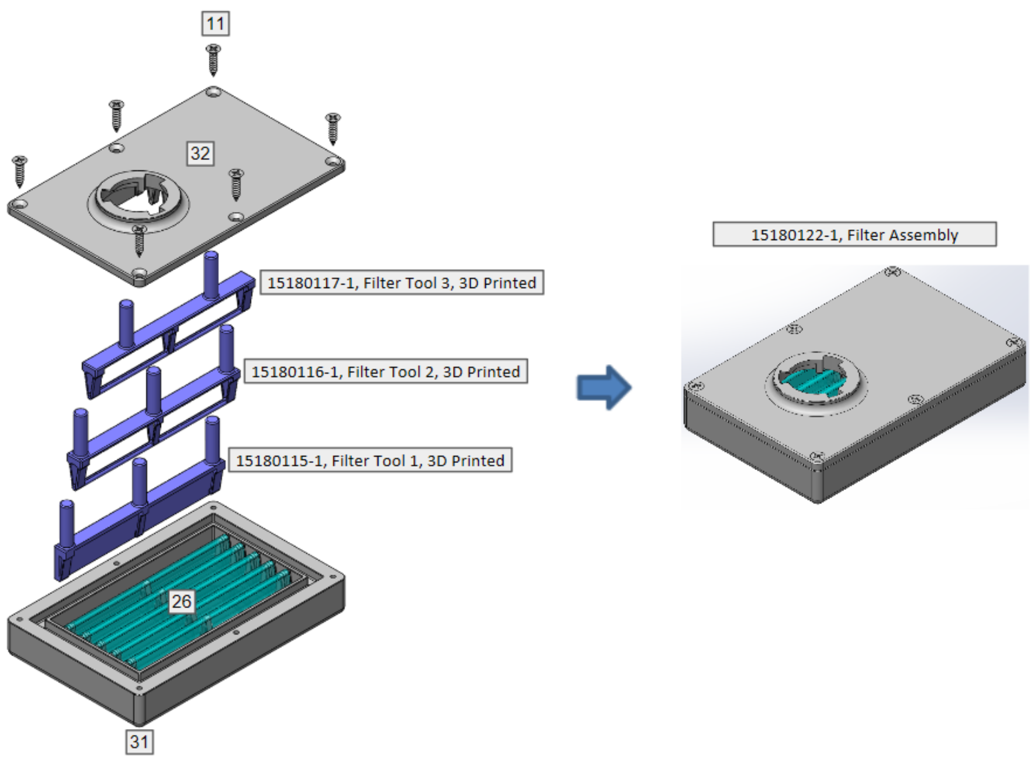


*Figure 6: Filter Assembly (10580122-1). 15180119-2 Seal, Rectangular, Filter Adapter (30) is not seen in this image but can be seen in the assembly steps below*

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1. Lay out the following components and tooling
    1.1. Screw, C-sink, Phillips (11)
    1.2. Seal, Filter Square (29)
    1.3. Hepa Filter (26)
    1.4. Helmet Filter Base (Sealed 3m) (31)
    1.5. Helmet Filter Cover (Sealed 3m) (32)
2. Cut the filter material (26)
    2.1. Cut an 84 mm X 138 mm piece from the hepa vacuum
        - Make sure that the filter is only two of the five sheets thick

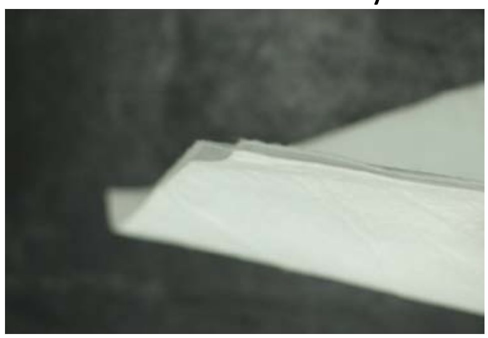

*Figure 7: Hepa Vacuum Bag Filter Material*

3. Create the Seal, Rectangular, Filter Adapter 15180119-2 (30)
    3.1. Use 15180118-2 (rectangular 3D printed template) and the Seal, Filter Material (29) to create a seal for the next step
        - A silver sharpie and a razor blade or exacto-knife would make this step easier

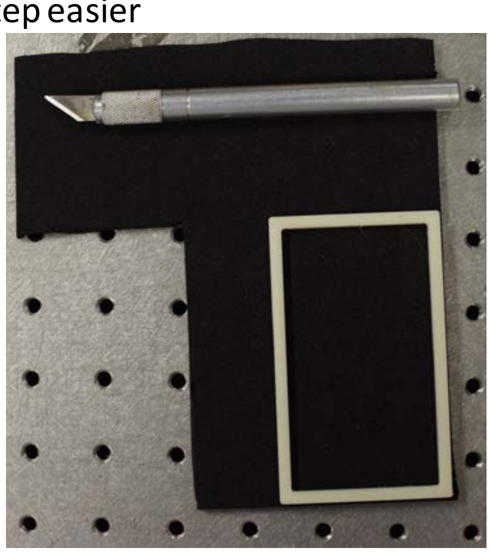

*Figure 8: 15180118-1 & Filter Seal Material*

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*Figure 9:* Seal, Rectangular, Filter Adapter (30)

4. Create 15180119-1 Seal, Round, Filter Adapter (Qty 3 Required)
   4.1. While the foam materials (29) and tools are out, use 15180118-1 (the 3D round printed seal template) to trace and cut the three seals
      - the foam material (29) is much thicker and differs in appearance from what is seen in the image below
      - You can fold the seal in half to cut the inner circle as shown below
   4.2. Set these three circular seals aside for assembly operations later on


*Figure 9a: Filter Assembly Round Seals (3 required)*

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5. Assemble the filter & filter housing assembly

5.1. Lay one of the 84 mm sides of the filter along the long side of the Helmet Filter Base (Sealed 3m) (31)

- This should be pretty intuitive

5.2. Lightly press Filter Tool 1 into the 1st slot of the Helmet Filter Base (Sealed 3m) (31)

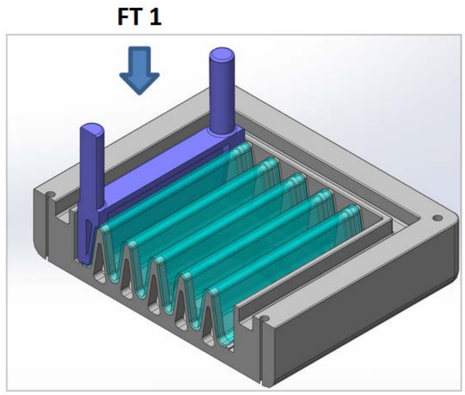


*Figure 10: Filter Tool 1 Insert into 1st slot*

5.3. Lightly Press Filter Tool 2 into the 2nd slot of the Helmet Filter Base (Sealed 3m) (31)

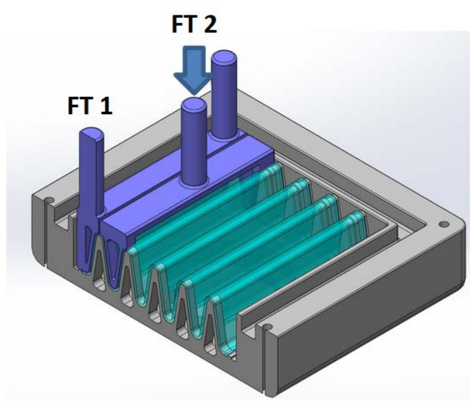


*Figure 11: Filter Tool 2 Insert into 2nd slot*

5.4. Lightly Press Filter Tool 3 into the 3rd slot of the Helmet Filter Base (Sealed 3m) (31)

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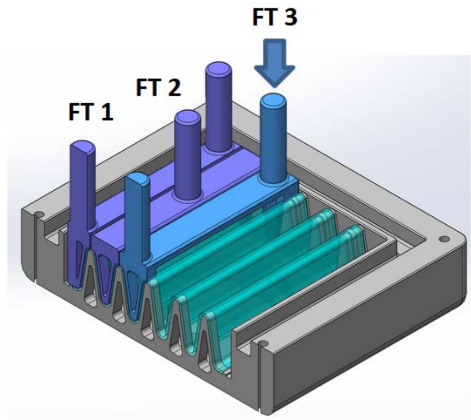

*Figure 12: Filter Tool 3 Insert into 3rd slot*

5.5. Slowly remove Filter Tool 2 and lightly press it into the 4th slot of the Helmet Filter Base (Sealed 3m) (31)

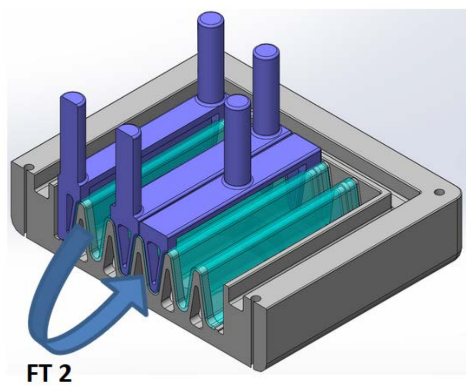

*Figure 13: Filter Tool 2 Removal & Insert into 4th slot*

5.6. Slowly remove Filter Tool 3 and lightly press it into the 5th slot of the Helmet Filter Base (Sealed 3m) (31)

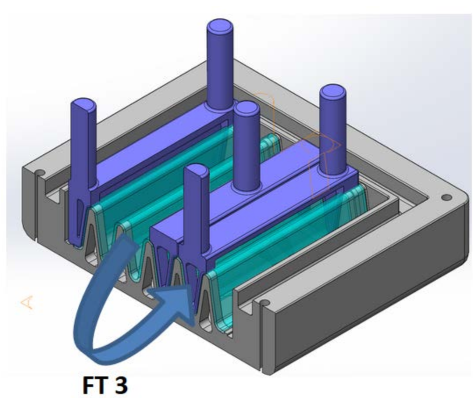

*Figure 14: Filter Tool 3 Removal & Insert into 5th slot*

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5.7. Slowly remove Filter Tool 1, rotate 180 degrees and lightly press it into the 6th slot of the Helmet Filter Base (Sealed 3m) (31)

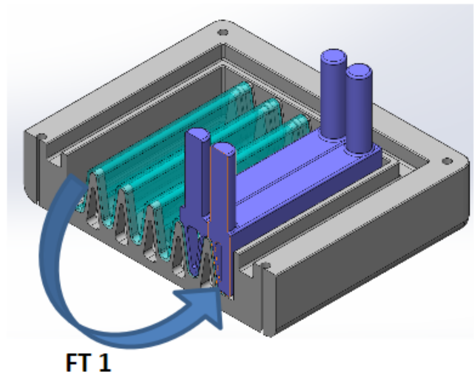


*Figure 15: Filter Tool 1 Removal & Insert into 6th slot*

5.8. Slowly remove Filter tool 2 and set aside

5.9. Slowly remove Filter Tool 1 & Filter Tool 3 and set aside

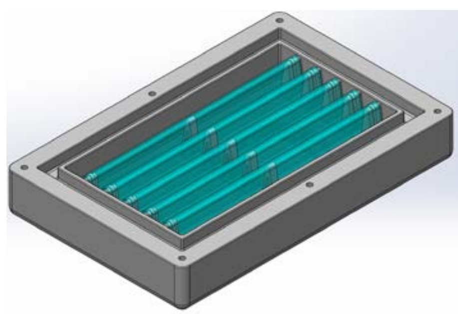

*Figure 16: Filter Tools Removal*

5.10. Insert Seal, Rectangular, Filter Adapter 15180119-2 (30) into Helmet Filter Base (Sealed 3m) (31)

- Use a flat head screwdriver to push the seal

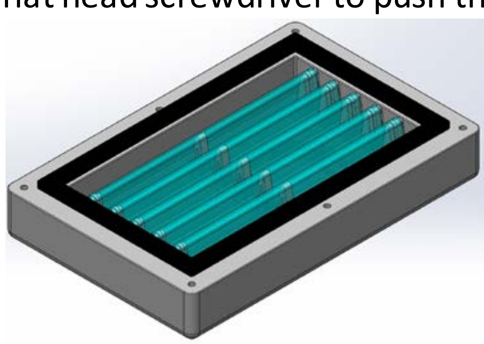

*Figure 17: Filter Seal Installation*

5.11. Place Helmet Filter Cover (Sealed 3m) (32) over Helmet Filter Base (Sealed 3m) (31)

- **This is very important, make sure that the inlet and outlet of the covers are inline with one another**

5.12. Fasten down all six #4 Size by 1/2" long screws

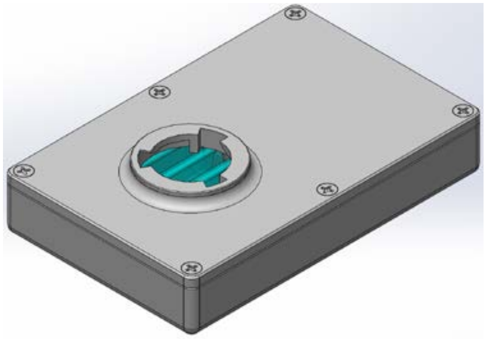

*Figure 18: Filter Housing Assembly*

## Inlet Filter Assembly (JPL PN 15180123-1)

| | QTY -1 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180123 Inlet Filter Assembly** | 4 | 11 | 90065A110 | Screw, C-Sink, Phillips | 18-8 CRES, #4-1/2 in long | McMaster-Carr |
| | 1 | 26 | 53291 Style Q | HEPA Filter | HEPA Cloth Vacuum Bag | Kenmore |
| | 1 | 27 | 15180113-1 | Inlet Filter Base | ABS | 3D Printed Component |
| | 1 | 28 | 15180114-1 | Inlet Filter Cover | ABS | 3D Printed Component |

*Table 3:* 15180123-1 BOM

Both versions of the assembly use the same Inlet Filter Assembly.

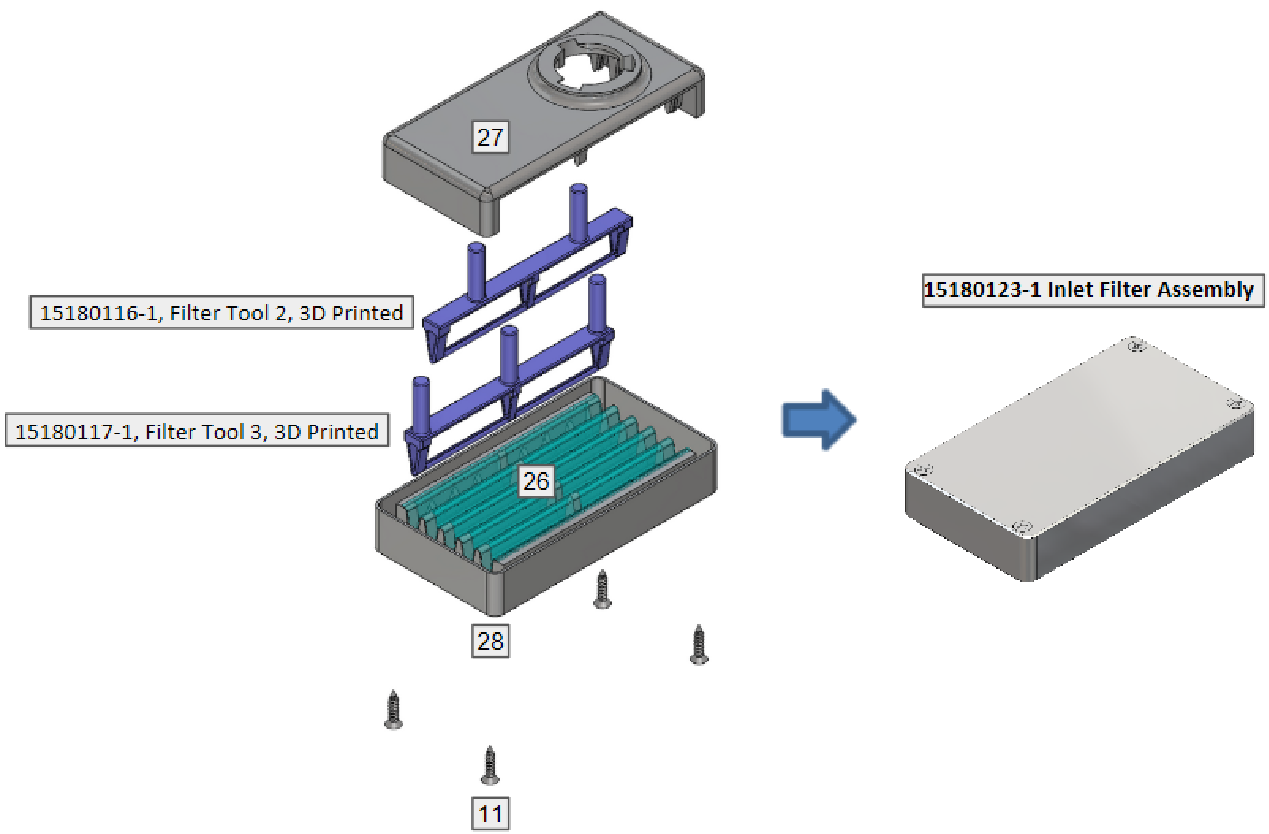


*Figure 19: Exploded view of Inlet Filter Assembly*

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1. Lay out the following:
   1.1. Screw, C-sink, Phillips (11)
   1.2. Hepa Filter (26)
   1.3. Inlet Filter Base (27)
   1.4. Inlet Filter Cover (28)
   1.5. 15180116-1, Filter Tool 2, 3D Printed
   1.6. 15180117-1, Filter Tool 3, 3D Printed
2. Cut the filter material (26)
   2.1. Cut an 84 mm X 138 mm piece from the hepa vacuum
      - Make sure that the filter is only two of the five sheets thick

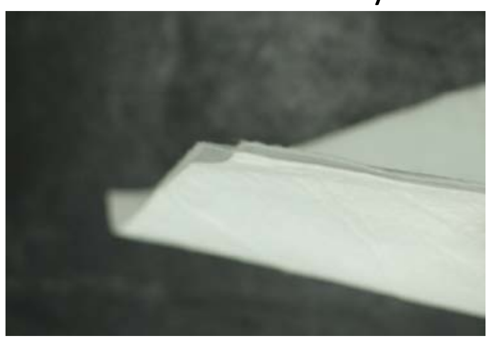

*Figure 20: Hepa Vacuum Bag Filter Material*

3. Assemble the filter & filter housing assembly
   3.1. Lay one of the 84 mm sides of the filter along the long side of the Inlet Filter Cover (28)
      - This should be pretty intuitive
   3.2. Lightly press Filter Tool 3 into the 1st slot of the Inlet Filter Cover (28)

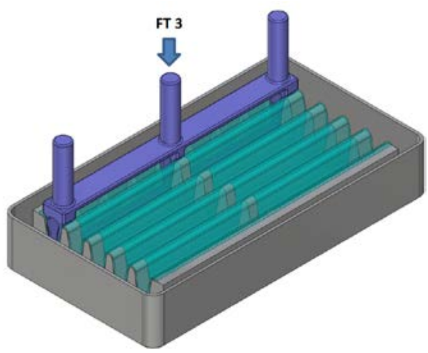


*Figure 21: Filter Tool 3 Insert into 1st Slot*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

3.3. Lightly Press Filter Tool 2 into the 2nd slot of the Inlet Filter Cover (28)

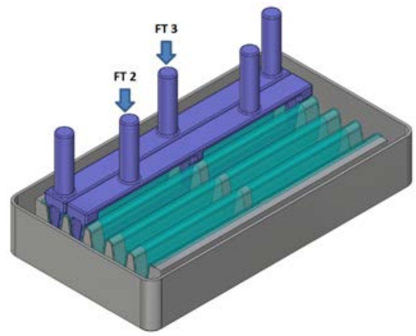


*Figure 22: Filter Tool 2 Insert into 2nd Slot*

3.4. Slowly remove Filter Tool 3 and lightly press it into the 3rd slot of the Inlet Filter Cover (28)

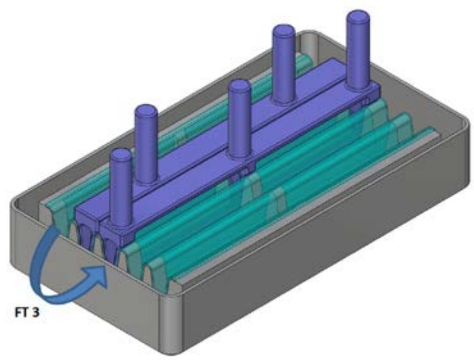


*Figure 23: Filter Tool 3 Removal & Insert into 3rd Slot*

3.5. Slowly remove Filter Tool 2 and lightly press it into the 4th slot of the Inlet Filter Cover (28)

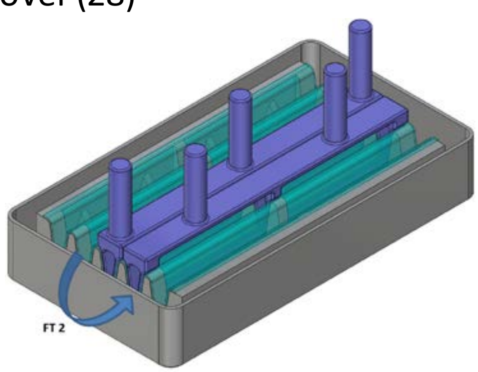


*Figure 24: Filter Tool 2 Removal & Insert into 4th Slot*

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3.6. Slowly remove Filter Tool 3 and lightly press it into the 5th slot of the Inlet Filter Cover (28)

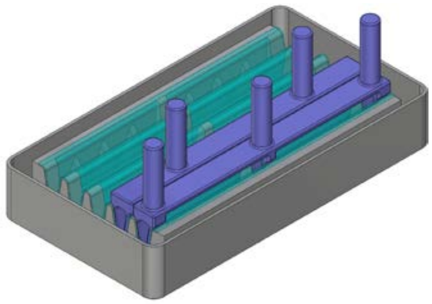

*Figure 25: Filter Tool 3 Removal & Insert into 5th slot*

3.7. Slowly remove Filter Tool 3 & then Filter Tool 2 and set aside

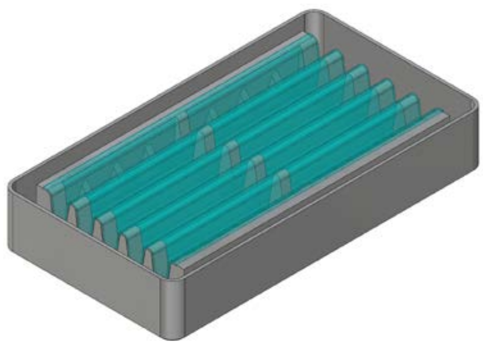

*Figure 26: Filter Tools Removal*

3.8. Place the Inlet Filter Base (27) over the Inlet Filter Cover (28)

*Figure 27: Filter Base Cover Installation*

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3.9. Carefully lift the current assembly and Rotate 180 degrees, and set down on a flat surface to access the fastener hole locations

*Figure 28: Inlet Filter Pre Fastener Installation*

3.10. Fasten down all four #4 Size by 1/2" long screws

*Figure 29: Inlet Filter Housing Assembly*

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# Low Flow Sensor and Electronics (15180121-1)

| | QTY -1 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180121 Low Flow Sensor & Electronics** | 4 | 33 | 96817A209 | Thread-Forming Screws for Thin Plastic | M2 Size, 6 mm Long | McMaster-Carr |
| | 1 | 34 | SFM3300-250-D | Flowmeter | | Sensirion |
| | 1 | 35 | | Power Switch (2 state toggle switch) | | Amazon |
| | 1 | 36 | A000005 | Arduino Nano | Controller for alarm system | Arduino |
| | 1 | 37 | MP1584EN | Voltage regulator | for Arduino | WGCD |
| | 1 | 38 | Red LED with Leads | LED | for alarm system | TT Electronics |
| | 1 | 39 | 220 Ohm Resistor | Resistor | for LED pull up | Stackpole Electronics |
| | 1 | 40 | ECPB_SNAP_BK_3P | Prototype Board | | ElectroCookie |
| | 1 | 41 | a12081600ux0477 | Buzzer | | Uxcell |
| | 1 | 42 | | 1/8" x 4" Zip Ties | | |
| | 1 | 43 | Jumper wire kit | Jumper wires | for various electronics | Austor |

*Table 4: 15180121-1 BOM*

Both versions of the assembly use the same low flow sensor and electronics. The low flow sensor system requires a soldering of an alarm buzzer, alarm LED (and 220 Ohm pull up resistor), a flow sensor (SFM3300), Arduino Nano board, and a perforated board together to create the alarm system. The Software below is then installed using the Arduino Software (IDE) which is an open source format that can be installed using many different operating systems. The connections shown in the image below use a green colored dot to indicate the solder connections that are made on the back of the perforated board.

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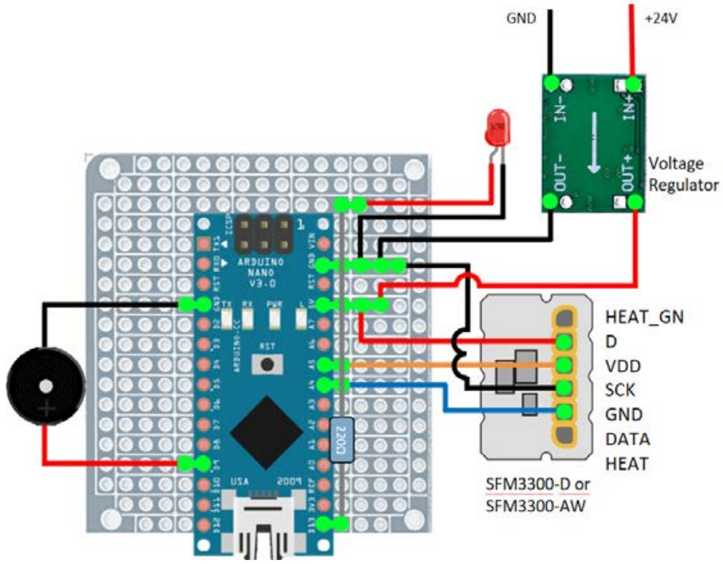


*Figure 29: Low Flowrate Alarm Schematic*

| Device | Arduino | Note |
|---|---|---|
| LED Positive Leg | Arduino D13 | INCLUDE 220 OHM RESISTOR |
| LED Negative Leg | Arduino Ground | |
| SFM3300 VDD | Arduino 5V | |
| SFM3300 SCK | Arduino A5 | |
| SFM3300 GND | Arduino Ground | |
| SFM3300 DATA | Arduino A4 | |
| Piezo Positive Leg | Arduino D9 | |
| Piezo Negative Leg | Arduino Ground | |
| Voltage Regulator OUT+ | Arduino 5V | SET VOLTAGE REGULATOR POTENTIOMETER TO 5V USING MULTIMETER |
| Voltage Regulator OUT- | Arduino Ground | |

*Table 5: Low Flow Rate Alarm Connections List*

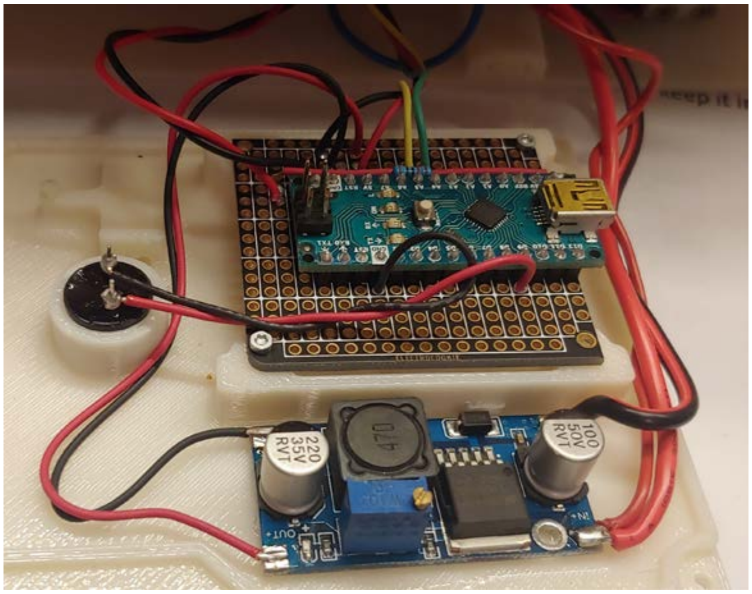

*Figure 30: Low Flow Rate Alarm Hardware (Using Alternative Voltage Regulator)*

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# Low Flow Rate Alarm Software

1. Download and install the latest version of the Arduino Software IDE
   https://www.arduino.cc/en/main/software
2. Set Board to Arduino Nano
3. Select COM Port for USB port used to connect with the Arduino Nano Board
4. Upload the software using the "Upload" button in the IDE via the USB to USB Mini Cable

```
// Start of software
// Open Source PAPR
#include <Wire.h>
// Create constants for identifying LED and buzzer
const int LED = 13; // LED
const int Buzzer = 9; // Buzzer

void setup() {
  // initialize the for the LED and Buzzer
  pinMode(LED, OUTPUT);
  pinMode(Buzzer, OUTPUT);
  Wire.begin();
  Serial.begin(115200);
  Wire.beginTransmission(byte(0x40));
  Wire.write(byte(0x10));
  Wire.write(byte(0x00));
  Wire.endTransmission();
}
void loop() {
  delay(100);
  Wire.requestFrom(0x40,2);
  uint16_t a = Wire.read();
  uint8_t  b = Wire.read();
  a = (a<<8) | b;
  float flow = ((float)a - 32768) / 120;
  Serial.println(abs(flow));
// set point for flow = 115 lpm
        if (abs(flow) <= 115) {
        // turn LED on:
        digitalWrite(LED, HIGH);
        tone(Buzzer, 2000);
  } else {
        // turn LED off:
        digitalWrite(LED, LOW);
        noTone(Buzzer);
  }
}
// End of software
```

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# Globe Tools Blower Assembly (15180124-1)

NOTE: This will assemble the electronics inside the blower housing, using the **Globe Tools blower**. If you are utilizing the ebmpapst blower, skip to next section "Blower Assembly (15180124-2)"

| | QTY -1 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180124-1 Blower Assembly** | 1 | 9 | 5388K24 | Worm Clamp / Plumbers Tape | optional | McMaster-Carr |
| | 1 | 10 | SKU: 5797 | Hose, CPAP | Tubing Slim Style, 48 inch Length | CPAP Supply USA |
| | 21 | 11 | 90065A110 | Screw, C-Sink, Phillips | #4, ½ in Length | McMaster-Carr |
| | 1 | 5 | 15180119-1 | Seal, Round, Filter Adapter | Multipurpose Neoprene Foam Strip | JPL Part |
| | 1 | 12 | 2935202 | 24V 4AH Battery | | greenworks |
| | 1 | 13 | SKU: 702554 | Clear Vinyl Tubing | 5/8 in. I.D. x 3/4 in. O.D. | Home Depot |
| | 1 | 15 | 15180123-1 | Inlet Filter Assembly | | JPL Assembly |
| | 1 | 16 | 15180121-1 | Low Flow Alarm System & Electronics Assembly | | JPL Assembly |
| | 1 | 18 | 15180101-1 | Housing, Globe Tools Blower | | 3D Printed Component |
| | 1 | 19 | 15180102-1 | Blower Lid, Universal Blower | | 3D Printed Component |
| | 1 | 20 | 15180103-1 | Electronics Lid, Globe Tools Blower | | 3D Printed Component |
| | 1 | 22 | 15180104-1 | Battery Holder, Universal Blower | | 3D Printed Component |
| | 2 | 23 | 15180105-1 | Belt Attachment, Universal Blower | | 3D Printed Component |

*Table 6: 15180124-1 BOM*

Note, reference Appendix C for technical specs pertaining to lithium ion battery packs (24V, 2AH & 4AH) and associated run times. Note, the 2AH lithium ion battery pack might suffice for your run time requirement and be half the price of the 4AH lithium ion battery pack.

# Globe Tools Blower Base Electronics (1518120-1)

This will assemble the electronics inside the blower housing, using the greenworks blower.

| | QTY -1 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180120-1 Blower Base Electronics** | 4 | 33 | 96817A209 | Thread-Forming Screws | for Thin Plastic, M2 Size, 6 mm Long | McMaster-Carr |
| | 1 | 44 | 8110K1 | Inline Fuse Holder | | McMaster-Carr |
| | 1 | 45 | 7460K521 | 2 amp ATM mini blade fuse | | |
| | 2 | 46 | 7060K88 | Single Crimp Male Quick Disconnect Terminal | | McMaster-Carr |
| | 1 | 50 | WM7040-24V | Control Potentiometer | | greenworks / Globe Tools |
| | 1 | 51 | | Brushless DC Blower Control Board | | |
| | 1 | 52 | | Brushless DC Blower | | |
| | 1 | 53 | 16 Gauge Silicone wire | 16 Gauge Silicone wire | 18" of 16 AWG Wire | BNTECHGO |

*Table 7: 15180120-1 BOM*

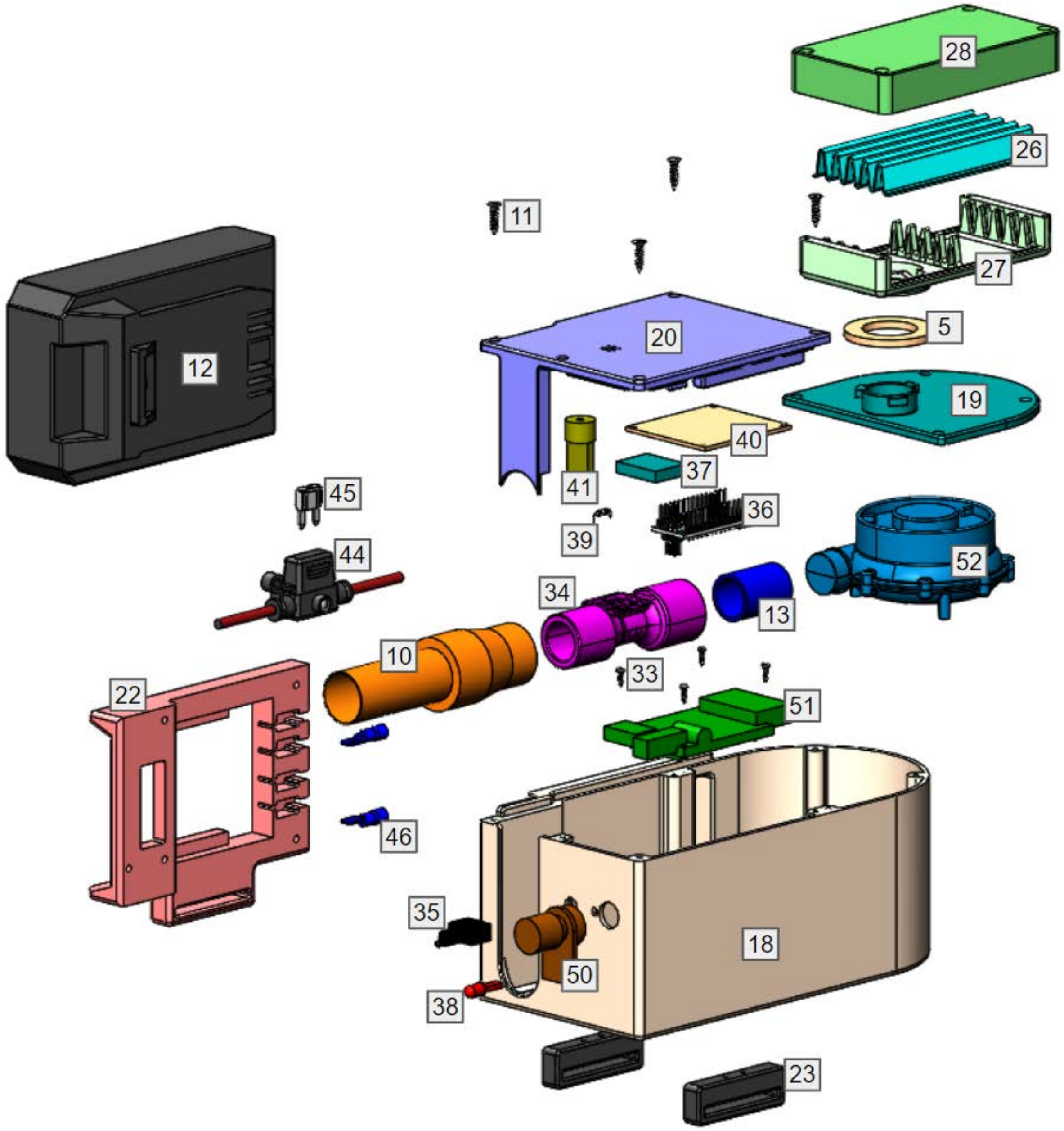



*Figure 31: Globe Tools blower assembly exploded view, with Item Number labeling.*

1. Layout all the 15180124-1 components.
2. Verify Ardunio and voltage regulator are wired as pictured in Figure 29.
3. Verify code is loaded onto Arduino.
   3.1. Utilize the latest version of Arduino software IDE.

3.2. More detailed instructions in "Low Flow Rate Alarm Software" section.

4. Verify Arduino Voltage Regulator OUT+ is set to 5V using multimeter.
5. Affix Belt Attachment (23) to Housing (18), with 4x screws (11).

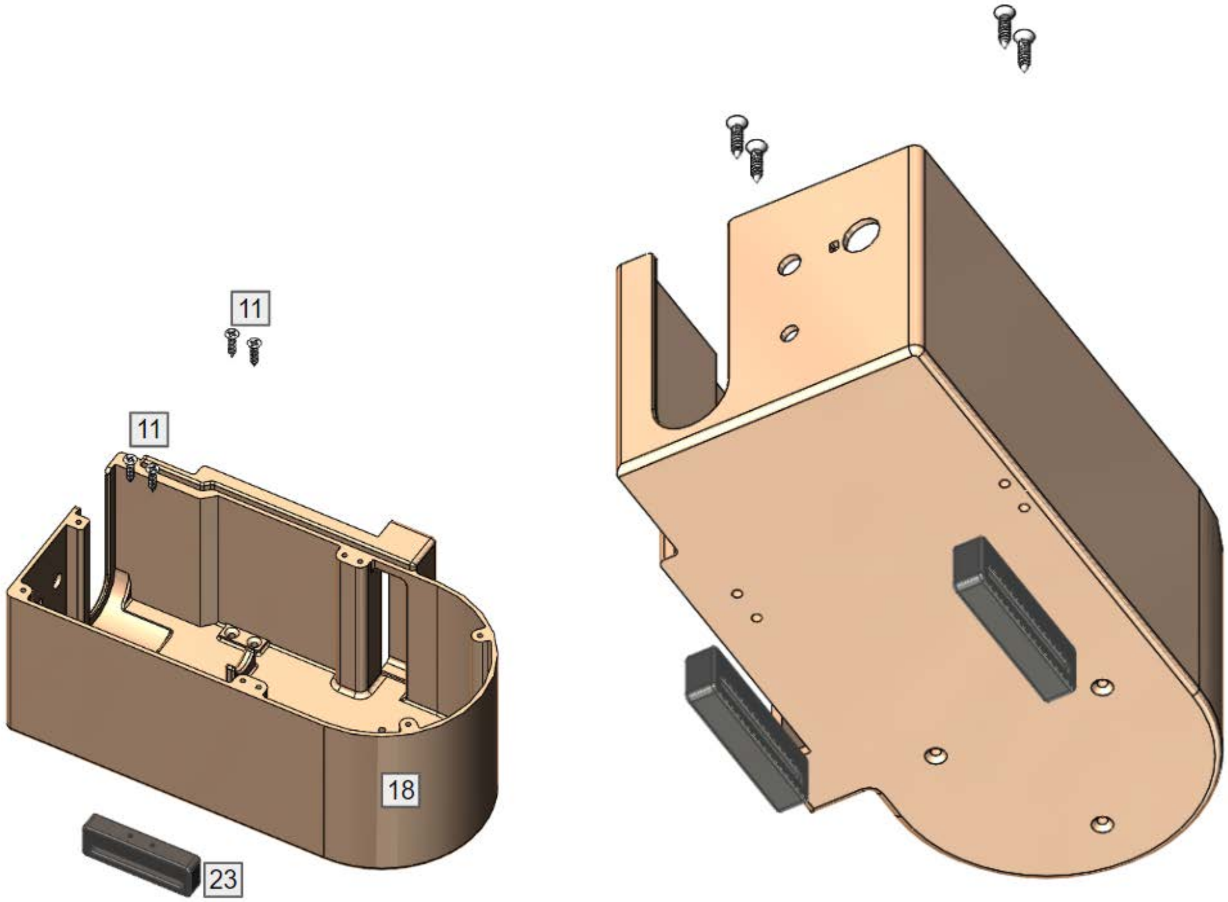
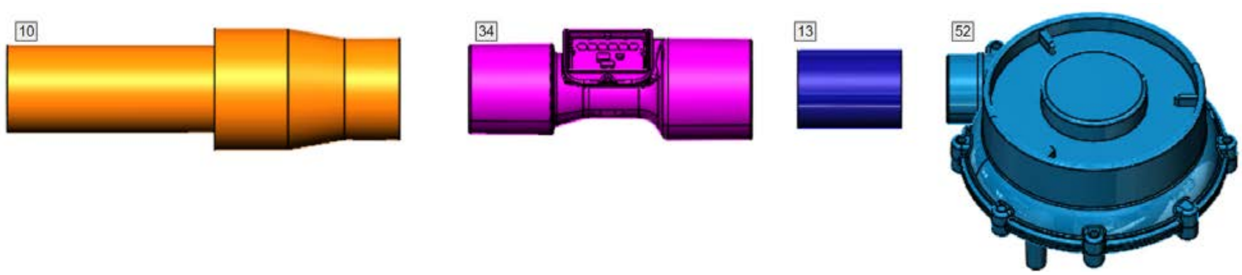



*Figure 32: Belt Attachment to Housing Assembly*

6. Connect hose, flow meter, and tube to blower
   6.1. Cut vinyl tubing (13) to 1" length
   6.2. Verify inlet of flow meter (34) is facing blower (52)
   6.3. Connect pieces together as pictured

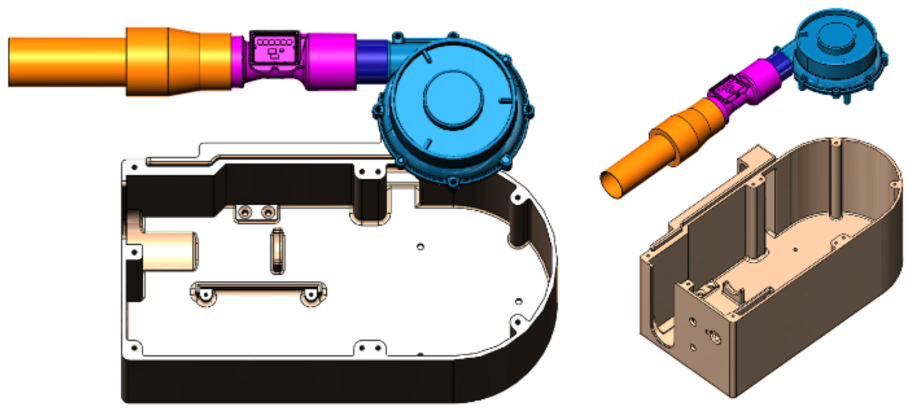



The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

*Figure 33: Fluid System Connection Order*


*Figure 34: Flow meter orientation*

7. Insert Blower (52) into the Housing (18)



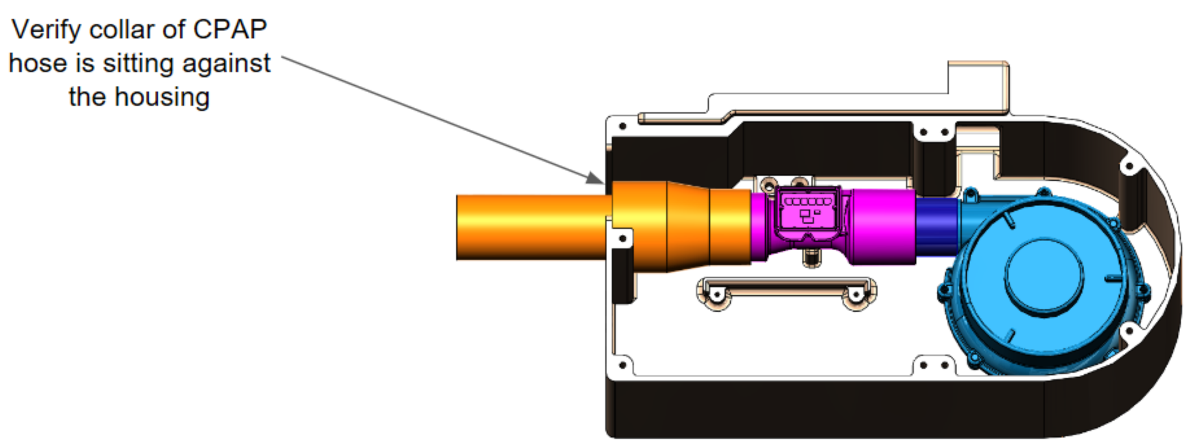



*Figure 35: Blower, Flowmeter & CPAP Placement*

8. Use Screws (11) to affix blower to Housing (18)
    8.1. Insert 3 of the screws (11) into the back face of the blower housing

Use screws to affix blower to housing

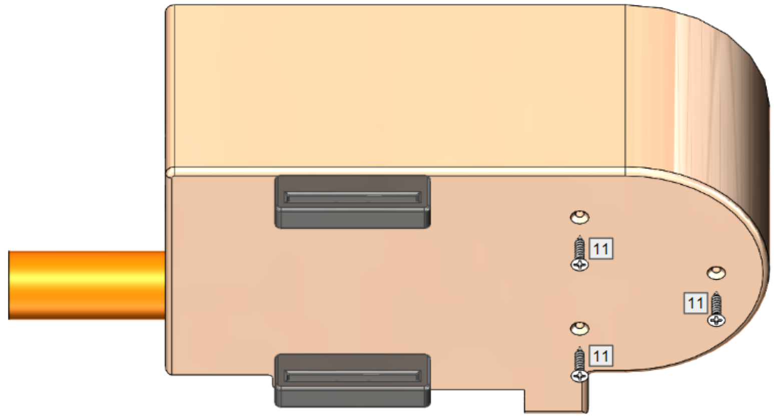



*Figure 36: Globe blower attachment screws*

9. Affix Potentiometer (50) to Housing (18)
    9.1. Remove knob from potentiometer
    9.2. From there, unthread nut from potentiometer
    9.3. Align clocking feature to slot in housing
    9.4. Thread nut back onto potentiometer
    9.5. Re-install potentiometer knob

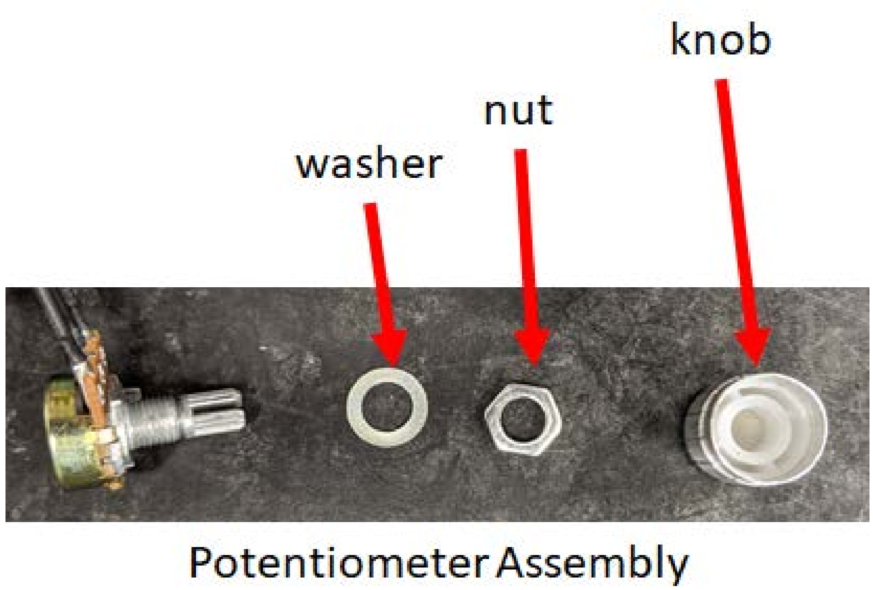



*Figure 37: Globe potentiometer nomenclature*

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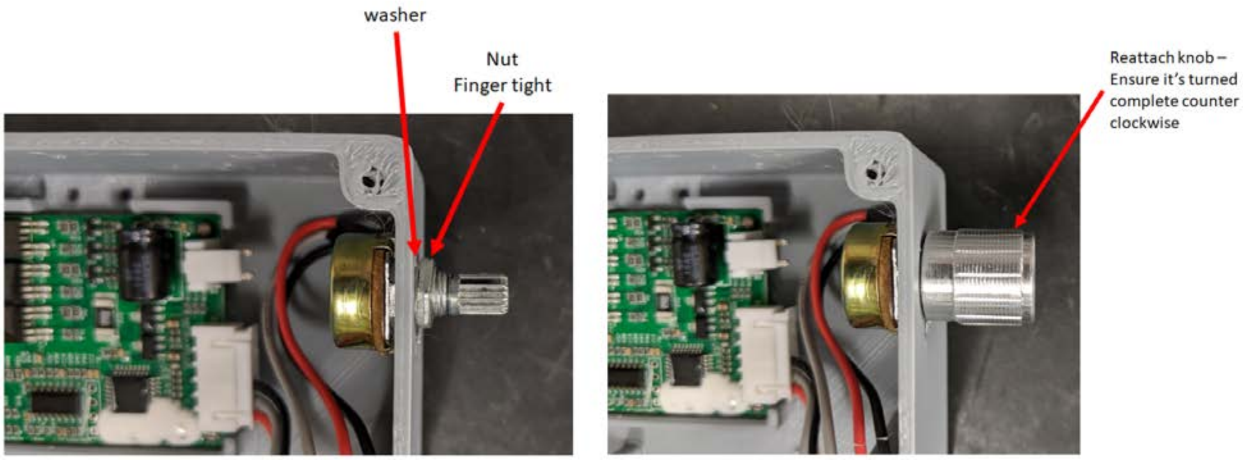


*Figure 38: Globe potentiometer assembly instructions*

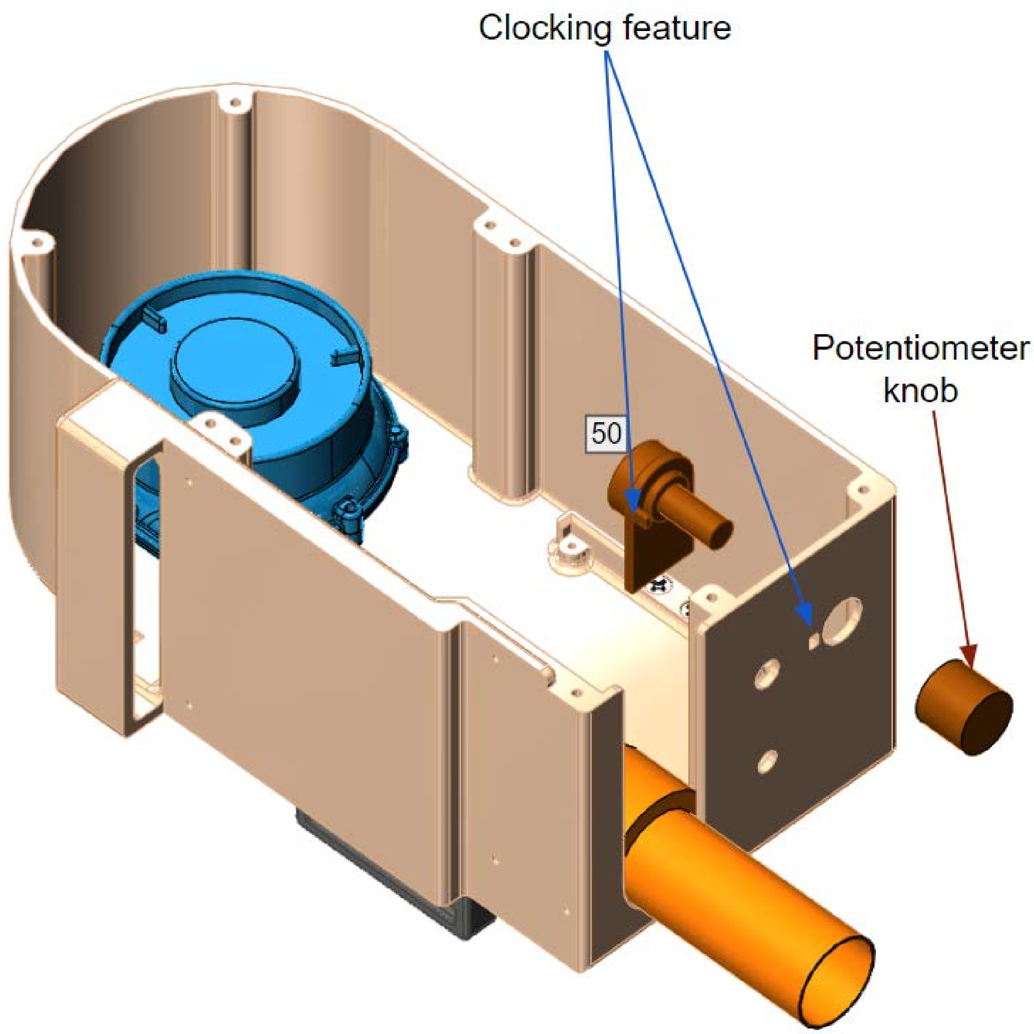


*Figure 39: Globe potentiometer attachment*

## 10. Affix Blower Control Board (51) to Housing (18)

10.1. Insert control board into housing
10.2. Use T6 on M2 fasteners (33)
10.3. Large connector to rear

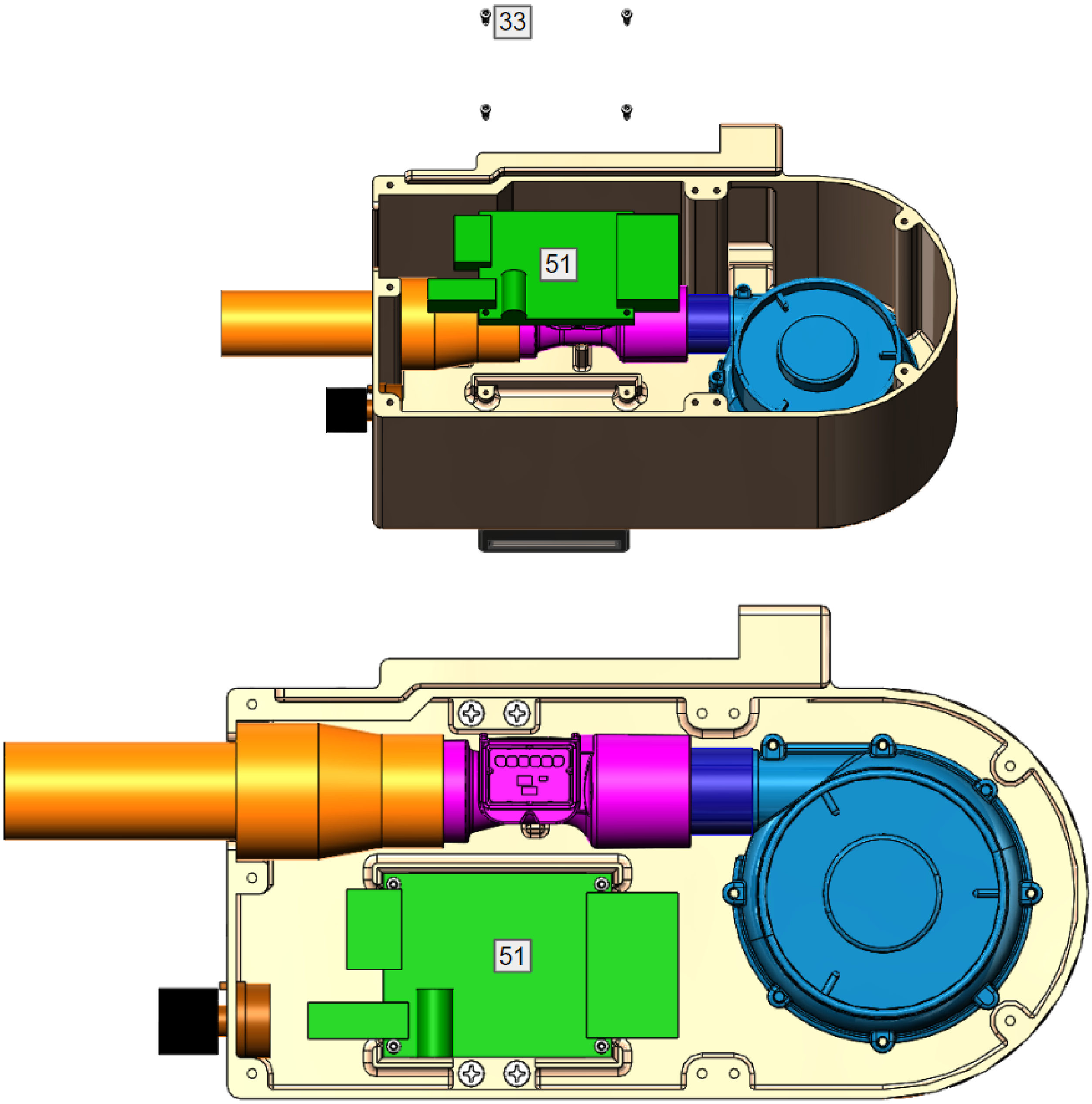


*Figure 40: Globe motor controller attachment*

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11. Connect Blower Motor and Potentiometer

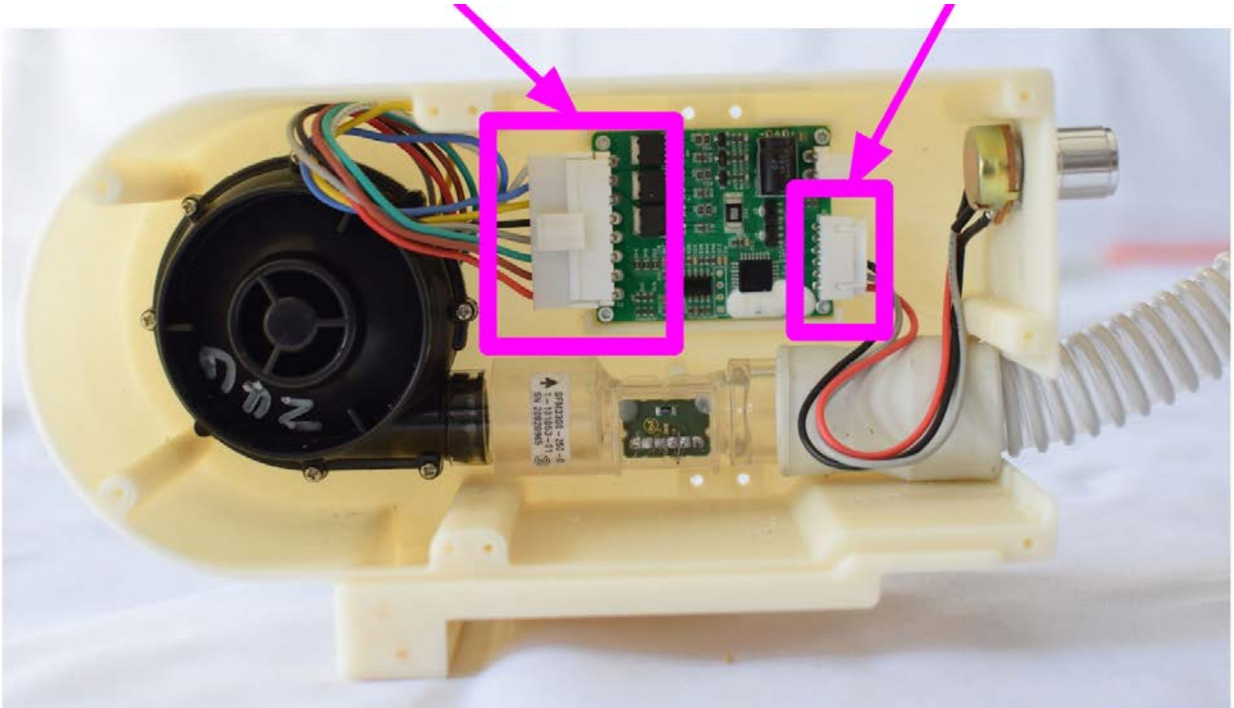

*Figure 41: Globe potentiometer and motor connection*

12. Solder all electronic items, per wiring diagram in Figure 43.

| Item No | Parts List Description | QTY |
|---|---|---|
| 20 | Electronics Lid, Globe Tools Blower | 1 |
| 33 | Thread-Forming Screws for Thin Plastic, M2 Size, 6 mm Long | 4 |
| 35 | Power Switch (2 state toggle switch) | 1 |
| 36 | Arduino Nano (Controller for alarm system) | 1 |
| 37 | Voltage regulator for Arduino | 1 |
| 38 | LED for alarm system | 1 |
| 39 | Resistor for LED pull up | 1 |
| 40 | Prototype Board | 1 |
| 41 | Buzzer | 1 |
| 42 | 1/8" x 4" Zip Ties | 1 |
| 43 | Jumper wires for various electronics | 1 |
| 44 | Inline Fuse Holder | 1 |
| 45 | 2 amp ATM mini blade fuse | 1 |
| 46 | Single Crimp Male Quick Disconnect Terminal | 1 |

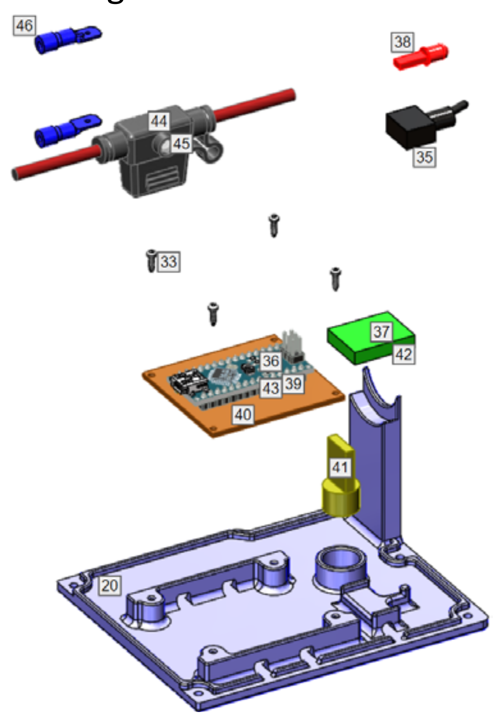


*Figure 42: Electronic Items to Solder*

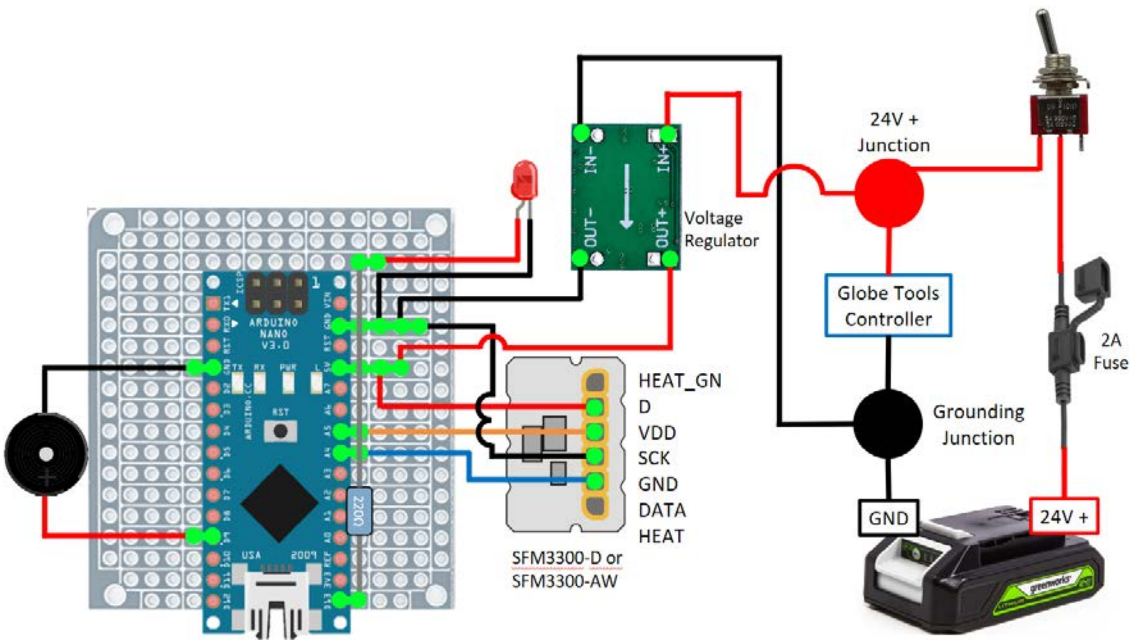


*Figure 43: Globe Tools Electronic Schematic*

13. More Electronics Assembly
    13.1. Connect the prototype board (40) with arduino (36) to the top lid. If M2 T6 screws (33) don't align, use slots for zip ties
    13.2. Affix Voltage Regulator for Arduino (37) to lid with zip tie
    13.3. Insert Buzzer (41) in slot as pictured, use hot glue to keep it in place

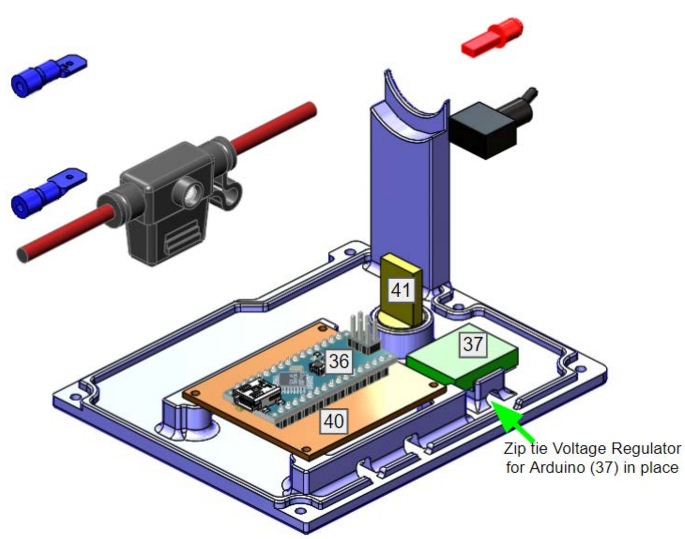


*Figure 44: Electronics Assembly*

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14. Place switch, LED, and fuse in housing
    14.1. Remove nut and washer from Power Switch (35).
    14.2. Slide Power Switch (35) into Housing (18), as pictured.
    14.3. Reattach nut and washer to Power Switch (35), on outside of housing (18)
    14.4. Attach LED light (38) in Housing (18), secure with hot glue
    14.5. Insert 2 Amp fuse (45) into Fuse Holder (44)
    14.6. Tuck Fuse Holder (44) to side, next to Flow Meter (34)

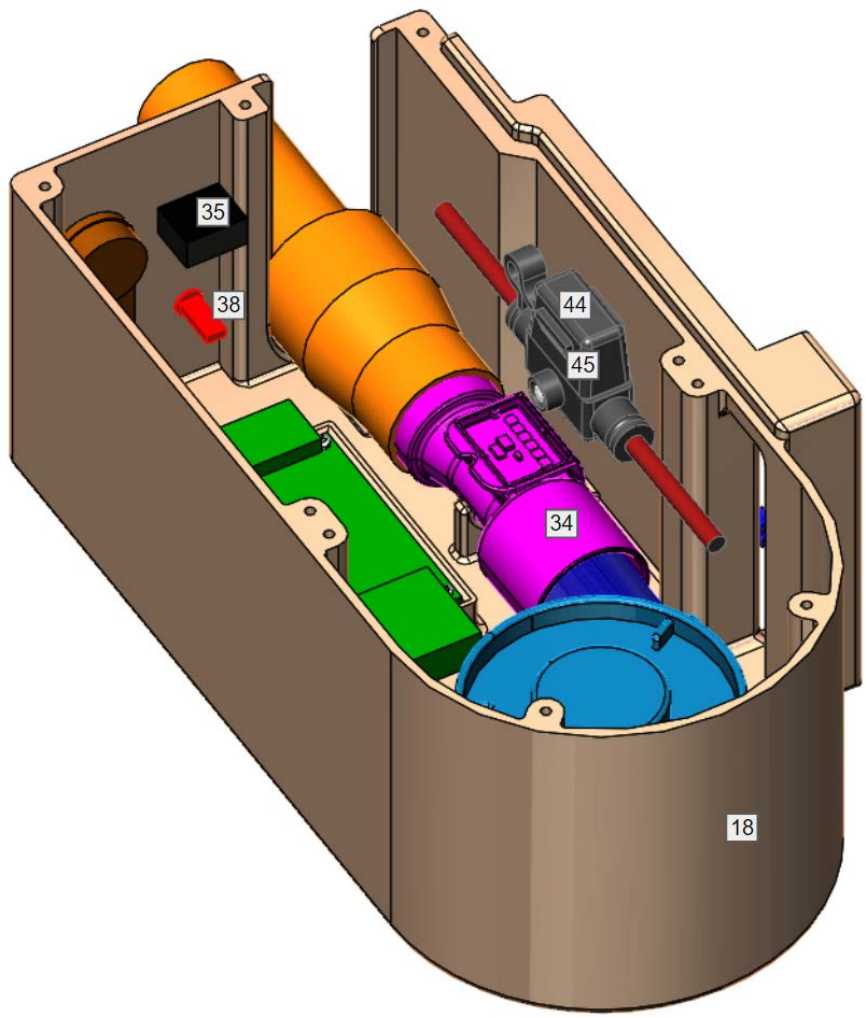


*Figure 45: Switch, LED, and Fuse Placement in Housing*

15. Route Power Supply Wires to Exterior of Housing (18)

  15.1. Route Quick Disconnect Terminals (46) through slot on side of housing (18)

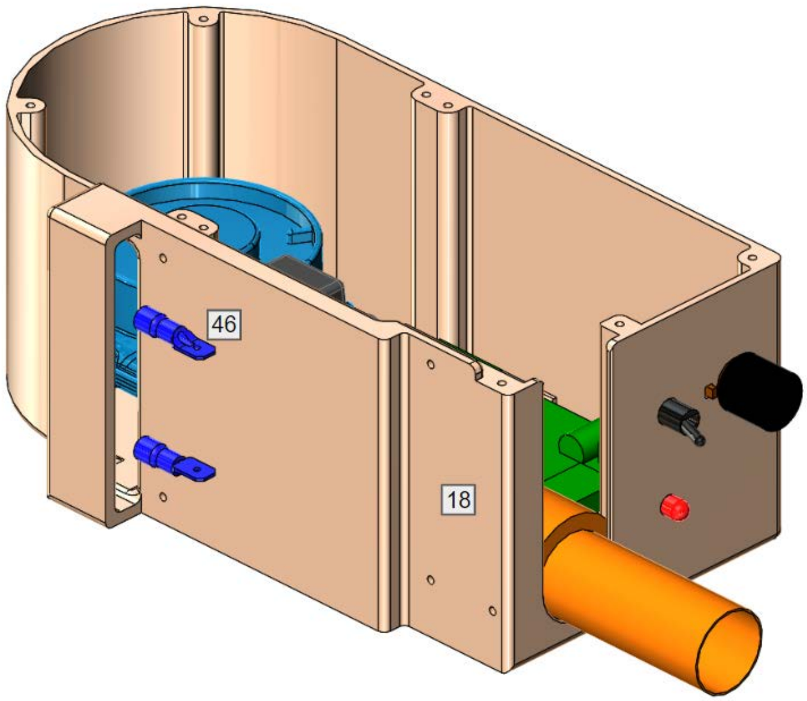


*Figure 46: Routing Power Supply Wires to External Housing*

16. Attach the lid to the housing

  16.1. Plug in power supply connector, to Blower Control Board (51).

  16.2. Carefully place Electronics Lid (20) onto Blower Housing (18)

  - Carefully wrap wires inside housing
  - Ensure no wires are pinched
  - Ensure no wires are pulled or connections are disconnected
  - Verify Quick Disconnect Terminals (46) still remain on exterior of Housing (18)

  16.3. Use 5 screws (11) to affix Lid (20) to Housing (18)

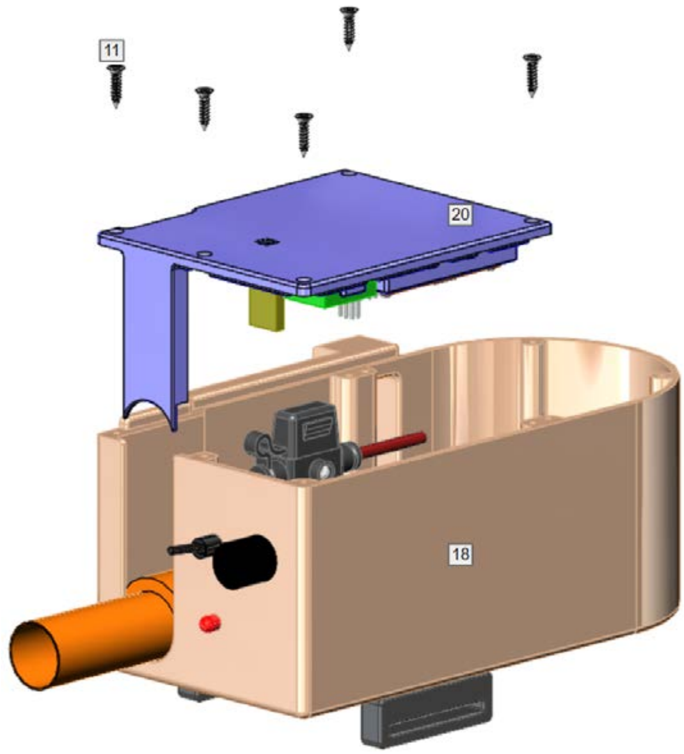


*Figure 47: Electronics Lid Attachment*

17. Affix battery holder
    17.1. Line up positive and negative Quick Disconnect Terminals (52) in Battery Holder (25) slots, so they align with positive and negative sides of the battery. Negative should be on the bottom.
        - Use a sharpie to denote on Battery Holder (25), which side is positive and negative
    17.2. Use screws (11) to affix Battery Holder (25) to Housing (21).

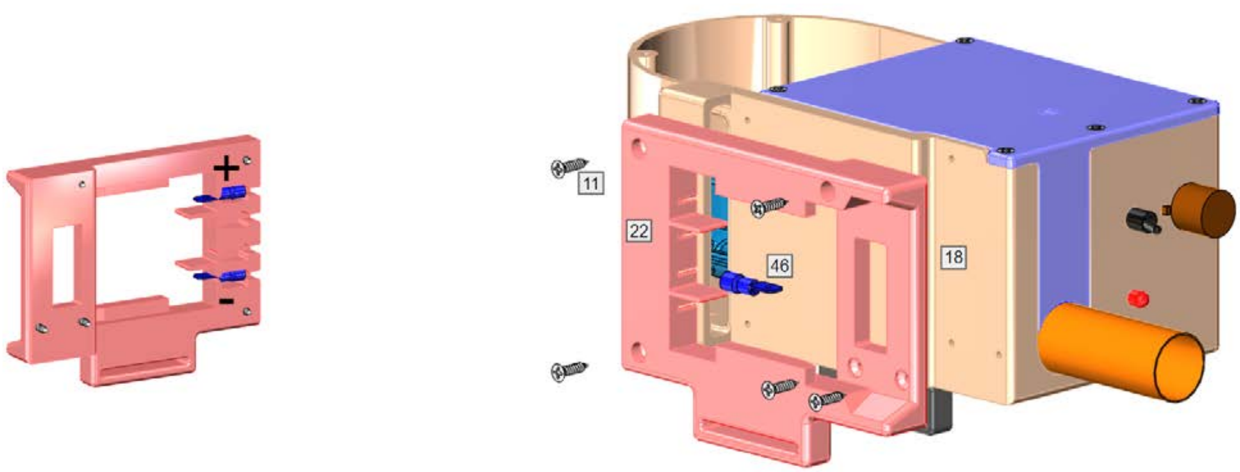


*Figure 48: Affix battery holder*

18. Attach the blower lid

18.1. Use 4 screws (11) to attach Blower Lid (19) to Housing (18)

- . Again be careful packaging any wires.

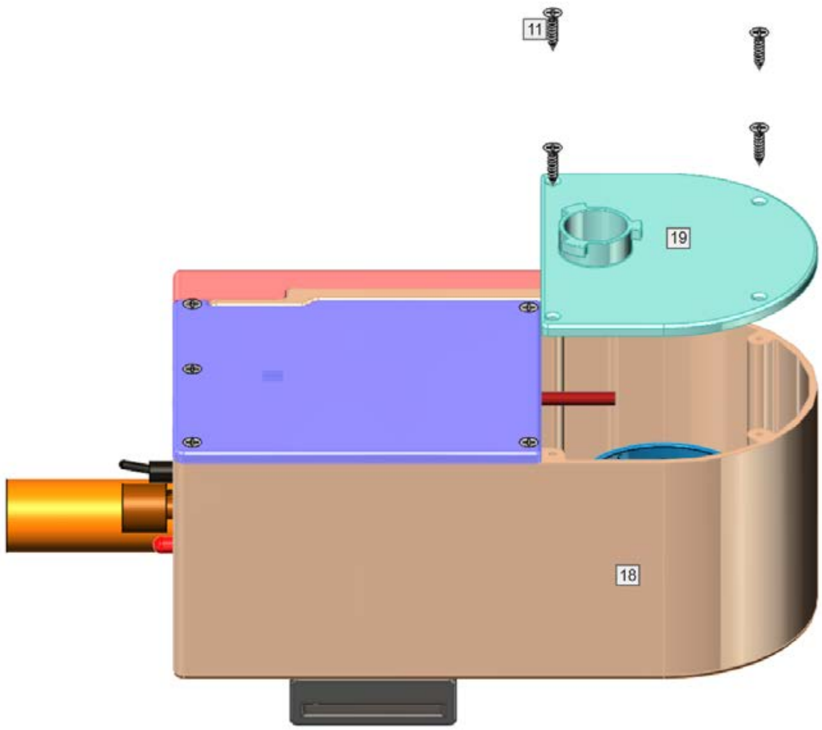


*Figure 49: Blower Lid Attachment*

19. Install circular foam seal on the Inlet Filter Assembly (5)

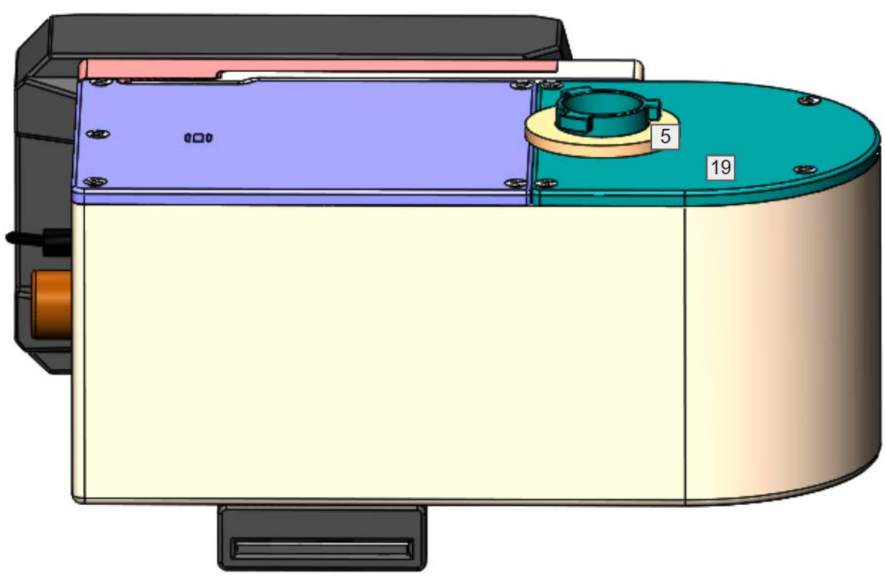


*Figure 50: Install Foam Gasket*

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20. Affix Inlet Filter Assembly (15180123) to Housing (18)

20.1. Check clocking slots to align correctly

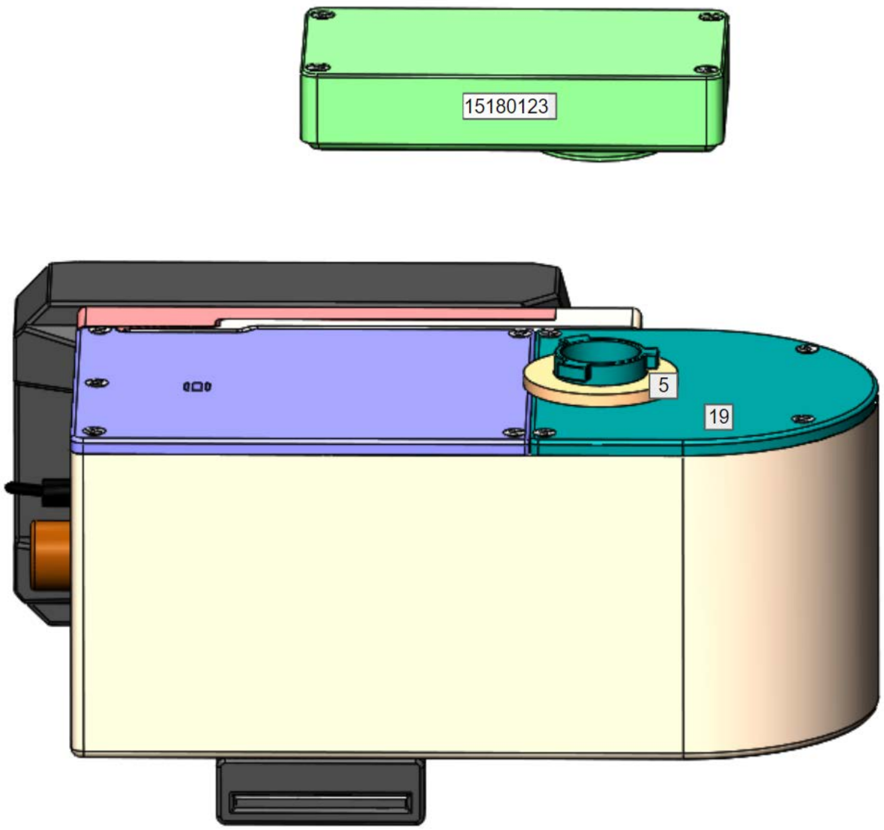


*Figure 51: Install Inlet Filter Housing*

21. Ensure Power Switch (40) is in off position

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22. Slide Battery (14) into Battery Holder (25)
    22.1. Verify battery is fully charged
    22.2. Verify positive/negative leads line up correctly with battery

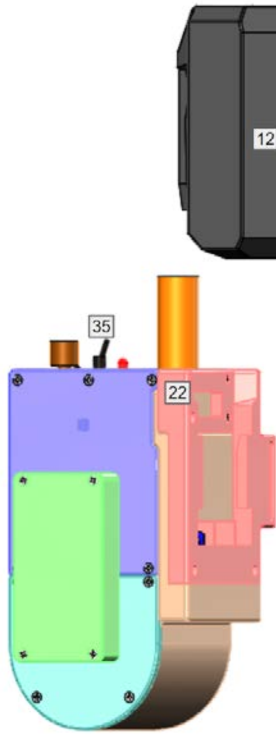


*Figure 52: Battery Installation*

23. Completed Blower Assembly

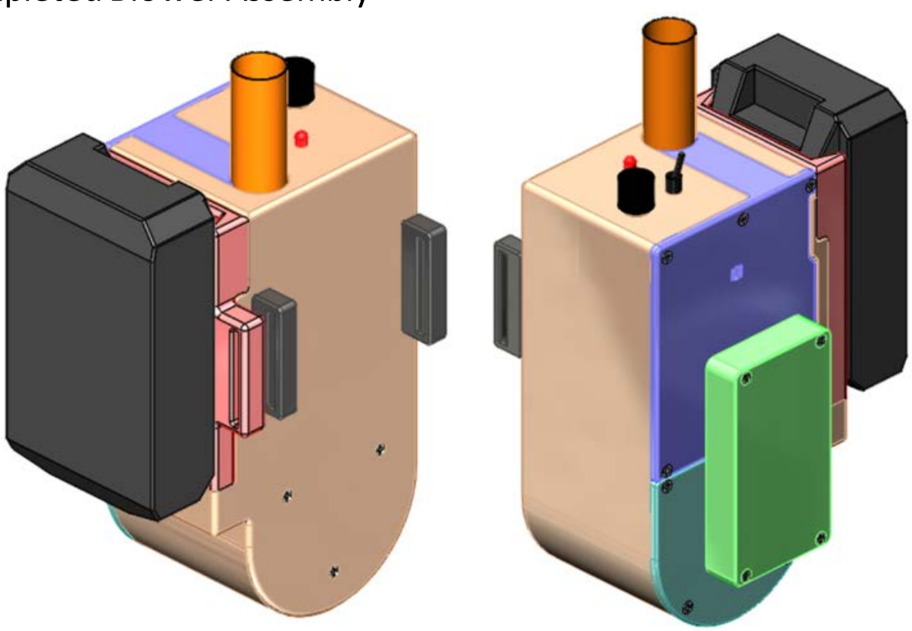

*Figure 53: Fully assembled 15180124-1 blower assembly*

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# ebmpapst Blower Assembly (15180124-2)

NOTE: This will assemble the electronics inside the blower housing, using the **ebmpapst blower**. If you are utilizing the Globe Tools blower, return to next section "Blower Assembly (15180124-1)"

| | QTY -2 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180124-2 Blower Assembly** | 1 | 9 | 5388K24 | Worm Clamp / Plumbers Tape | optional | McMaster-Carr |
| | 1 | 10 | SKU: 5797 | Hose, CPAP | Tubing Slim Style, 48 inch Length | CPAP Supply USA |
| | 23 | 11 | 90065A110 | Screw, C-Sink, Phillips | #4, ½ in Length | McMaster-Carr |
| | 1 | 5 | 15180119-1 | Seal, Round, Filter Adapter | Multipurpose Neoprene Foam Strip | JPL Part |
| | 1 | 12 | 2935202 | 24V 4AH Battery | | greenworks |
| | 1 | 14 | 5233K47 | Clear Vinyl Tubing | ⅞ in. ID x 1-⅛ in. OD | McMaster-Carr |
| | 1 | 15 | 15180123-1 | Inlet Filter Assembly | | JPL Assembly |
| | 1 | 16 | 15180121-1 | Low Flow Alarm System & Electronics Assembly | | JPL Assembly |
| | 1 | 17 | 15180101-2 | Housing, ebmpapst Blower | | 3D Printed Component |
| | 1 | 19 | 15180102-1 | Blower Lid, Universal Blower | | 3D Printed Component |
| | 1 | 21 | 15180103-2 | Electronics Lid, ebmpapst Blower | | 3D Printed Component |
| | 1 | 22 | 15180104-1 | Battery Holder, Universal Blower | | 3D Printed Component |
| | 2 | 23 | 15180105-1 | Belt Attachment, Universal Blower | | 3D Printed Component |
| | 1 | 24 | 15180107-1 | Blower Mount, ebmpapst Blower | | 3D Printed Component |
| | 1 | 25 | 15180108-1 | Controller Mount, ebmpapst Blower | | 3D Printed Component |

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

*Table 8: 15180124-2 BOM*

Note, reference Appendix C for technical specs pertaining to lithium ion battery packs (24V, 2AH & 4AH) and associated run times. Note, the 2AH lithium ion battery pack might suffice for your run time requirement and be half the price of the 4AH lithium ion battery pack.

# ebmpapst Blower Base Electronics (1518020-2)

| | QTY<br>-2 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|
| **15180120-2 Blower Base Electronics** | 1 | 44 | 8110K1 | Inline Fuse Holder | | McMaster-Carr |
| | 1 | 45 | | 2 amp ATM mini blade fuse | | McMaster-Carr |
| | 2 | 46 | 7060K88 | Single Crimp Male Quick Disconnect Terminal | | McMaster-Carr |
| | 1 | 47 | VA-RV45-PAPR | Control Potentiometer | | ebmpapst |
| | 1 | 48 | | Brushless DC Blower Control Board | | |
| | 1 | 49 | | Brushless DC Blower | | |
| | 1 | 53 | 16 Gauge Silicone wire | 16 Gauge Silicone wire | 18" of 16 AWG Wire | BNTECHGO |

*Table 9: 15180120-2*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

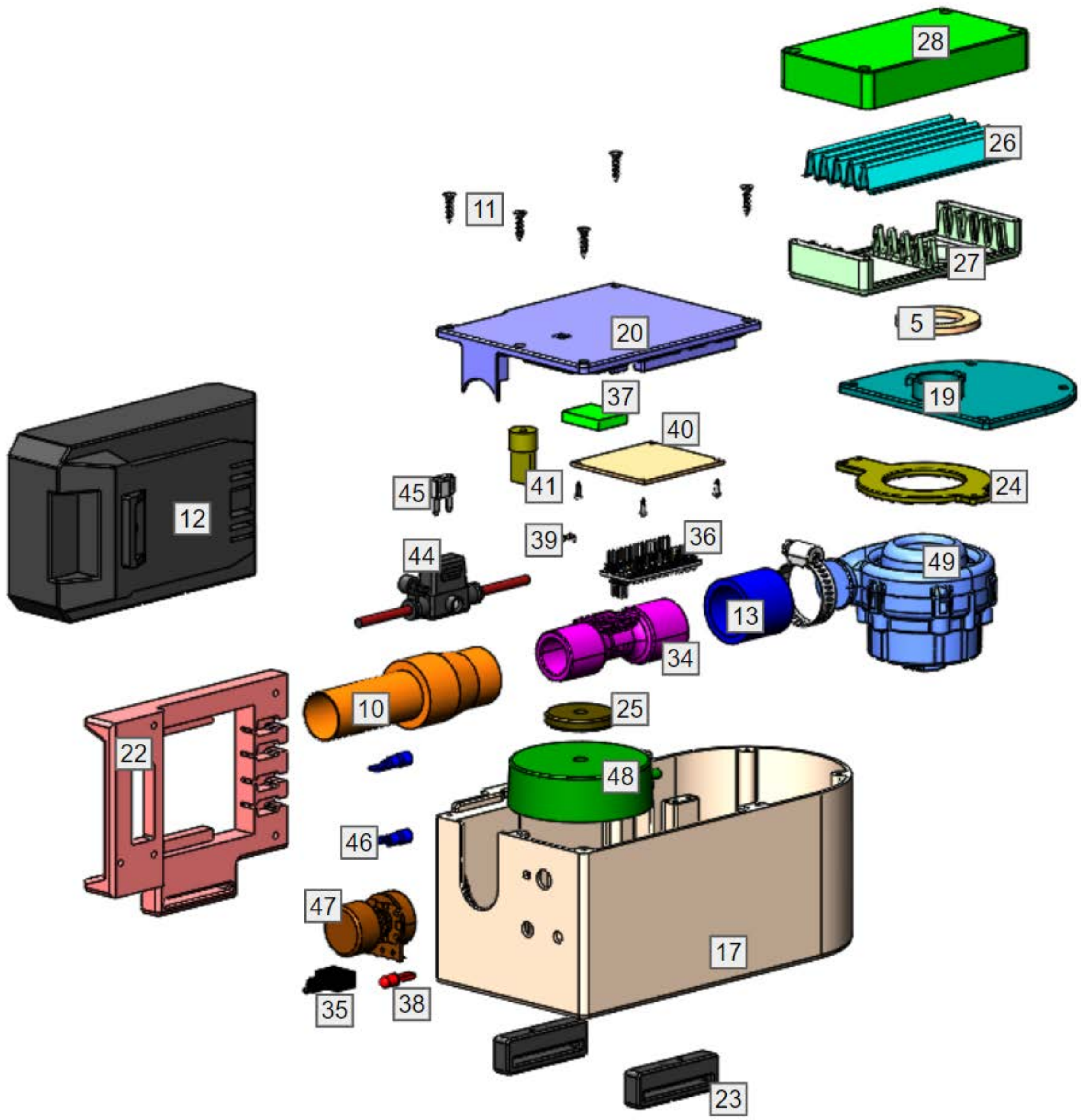


*Figure 54: ebmpapst blower assembly exploded view, with Item Number labeling*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

1. Layout all the 15180124-2 components
2. Verify Ardunio and voltage regulator are wired as pictured in Figure 29.
3. Verify code is loaded onto Arduino.
    3.1. Utilize latest version of Arduino software IDE.
    3.2. More detailed instructions in "Low Flow Rate Alarm Software" section.
4. Verify Arduino Voltage Regulator OUT+ is set to 5V using multimeter.
5. Affix Belt Attachment (23) to Housing (17), with 4x screws (11).

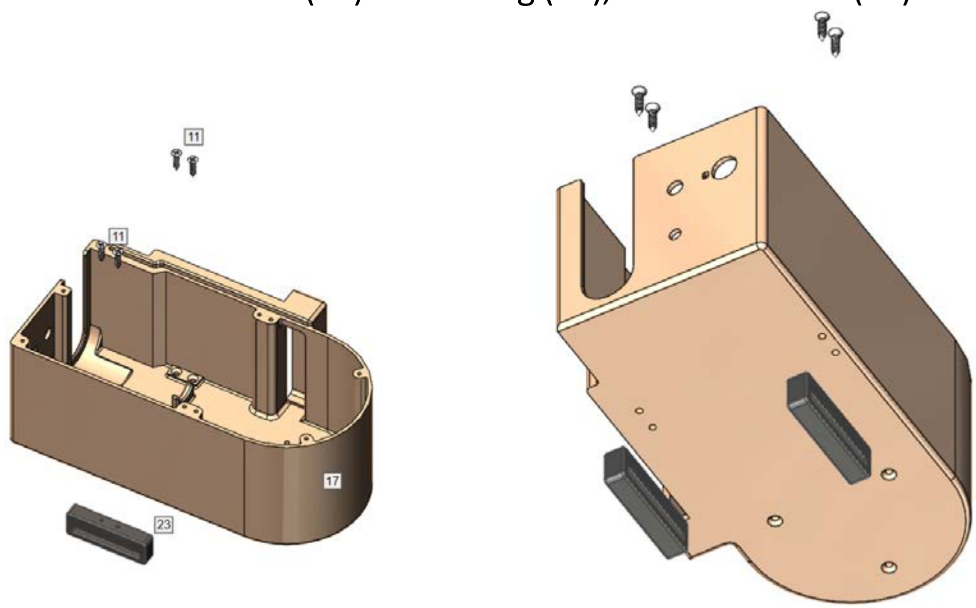


*Figure 55: Belt Attachment to Housing Assembly*

6. Connect hose, flow meter, and tube to blower
    6.1. Cut vinyl tubing (14) to 1" length
    6.2. Verify inlet of flow meter (34) is facing blower (49)
    6.3. Connect pieces together as pictured
        6.3.1. Use Worm Clamp (9) to keep tube connected to Blower

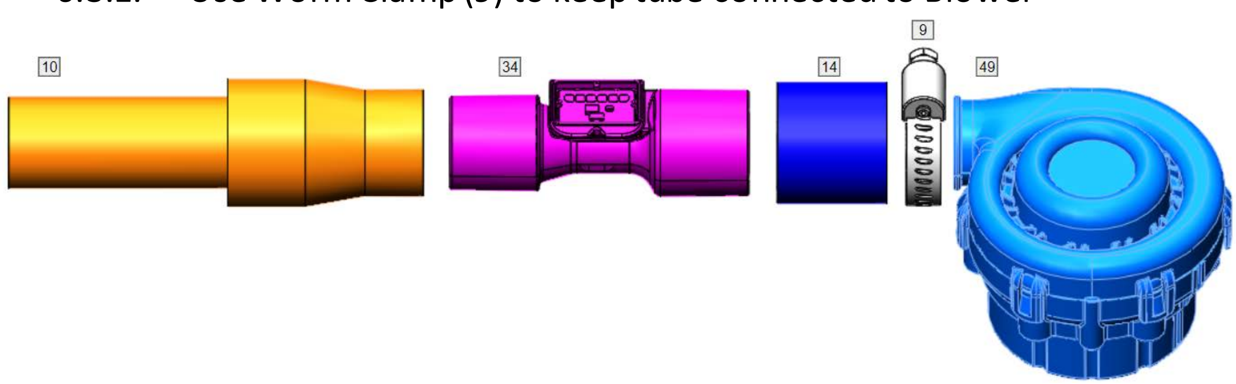


*Figure 56: Fluid System Connection Order*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration


*Figure 57: Flow meter orientation*

7. Insert blower controller into housing
    7.1. Place Control Board (48) so that leads point towards Blower (49)
    7.2. Use Controller Mount (25) and screw (11) to hold Control Board (48) in place

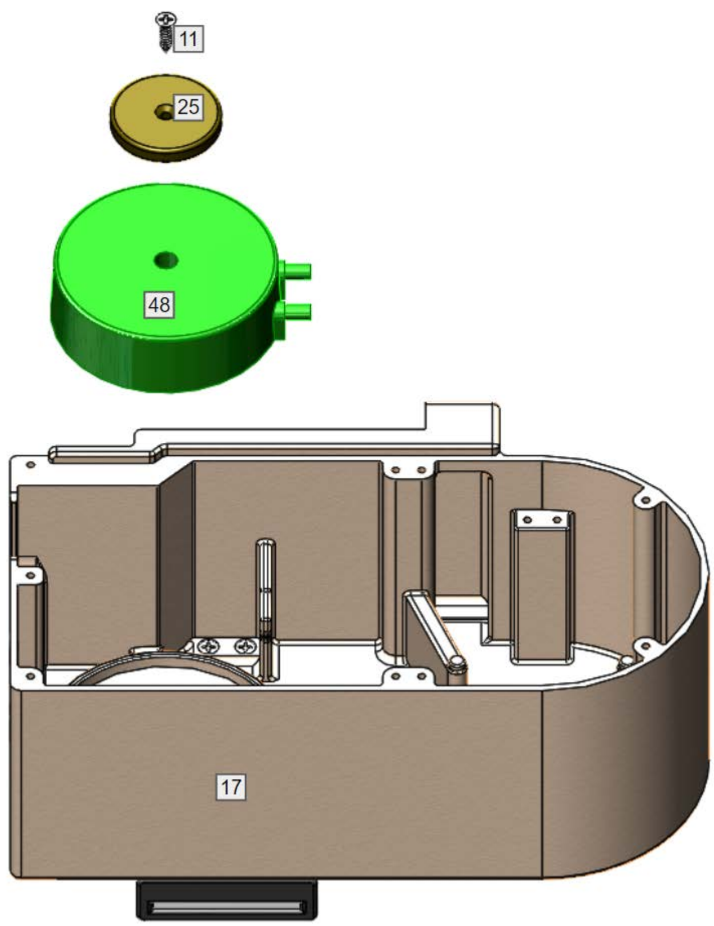


*Figure 58: ebmpapst motor controller attachment*

8. Place blower with hose couplings in housing

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8.1. Connect to blower motor controller before inserting

8.2. Align 3x flat screw mount post on blower with 3x housing risers

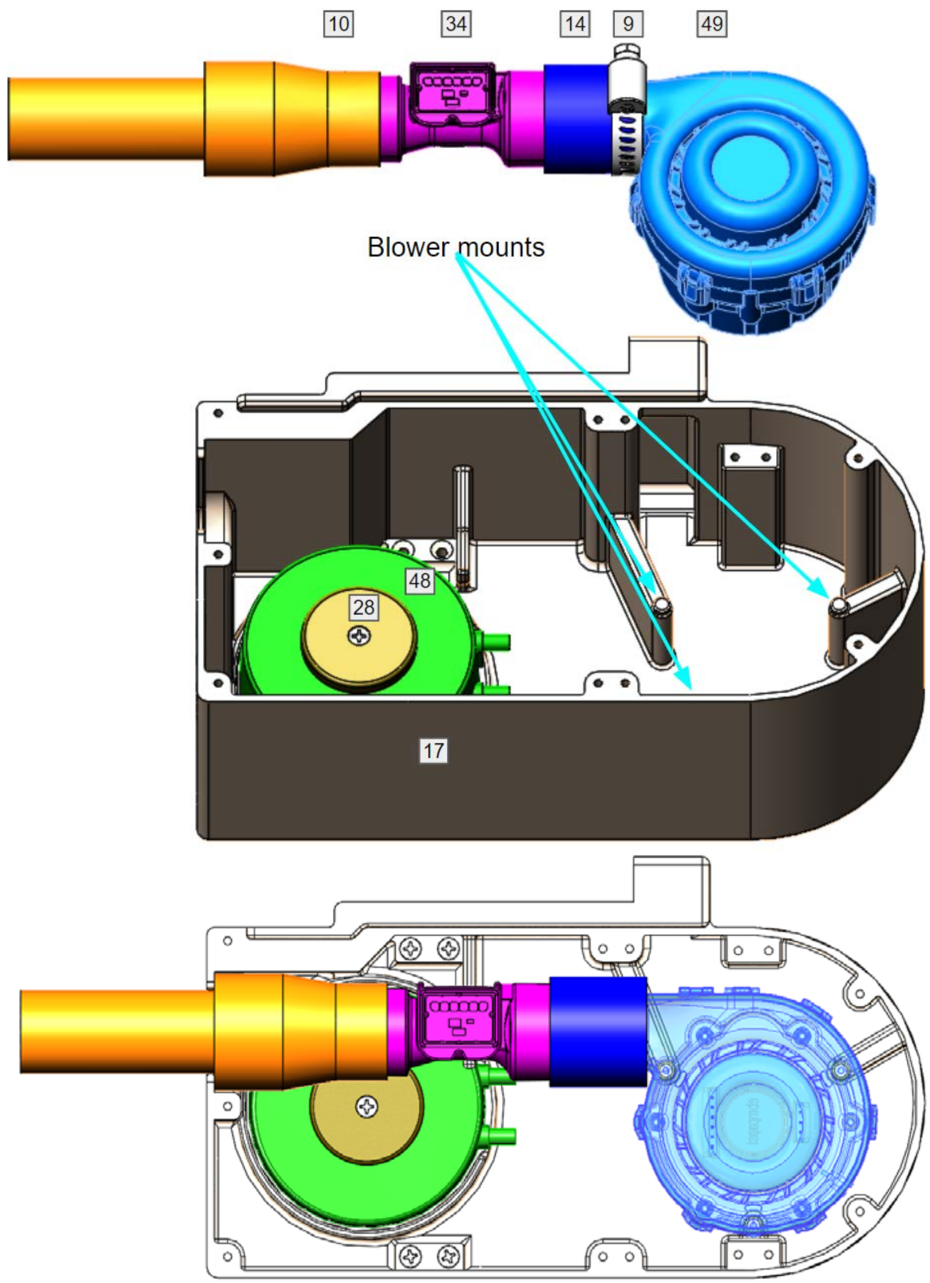


*Figure 59: Blower, Flowmeter & CPAP Placement*

9. Use Blower Mount (24) and screws (11) to secure Blower (49)

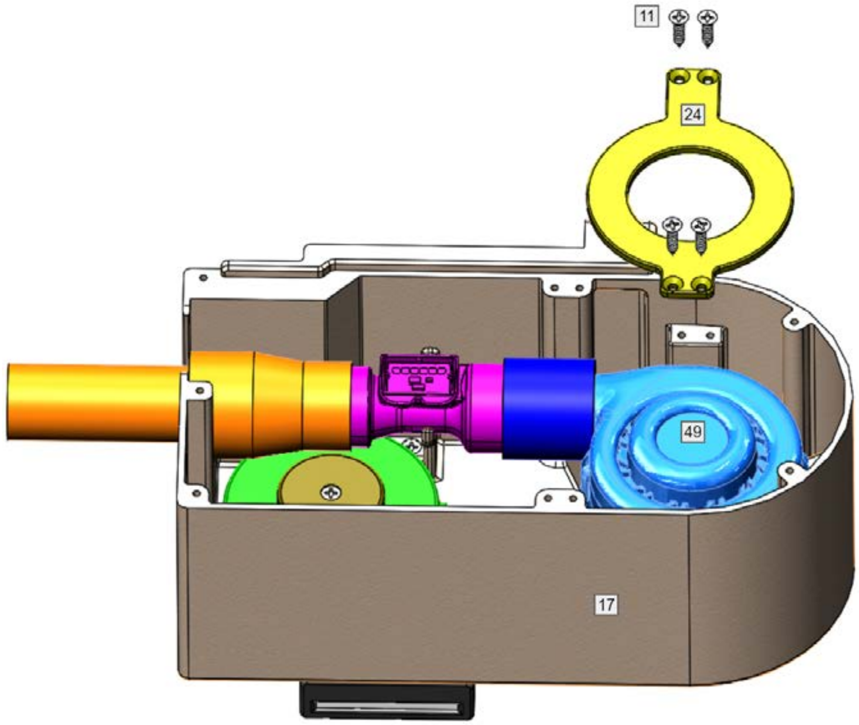


*Figure 60: Secure Blower to Housing*

10. Attach potentiometer (47)
    10.1. Remove knob, nut, and washer from top of potentiometer
    10.2. Insert potentiometer into housing, paying attention to clocking
    10.3. Reaffix washer, nut, and knob to potentiometer. Ensuring they are finger-tight.

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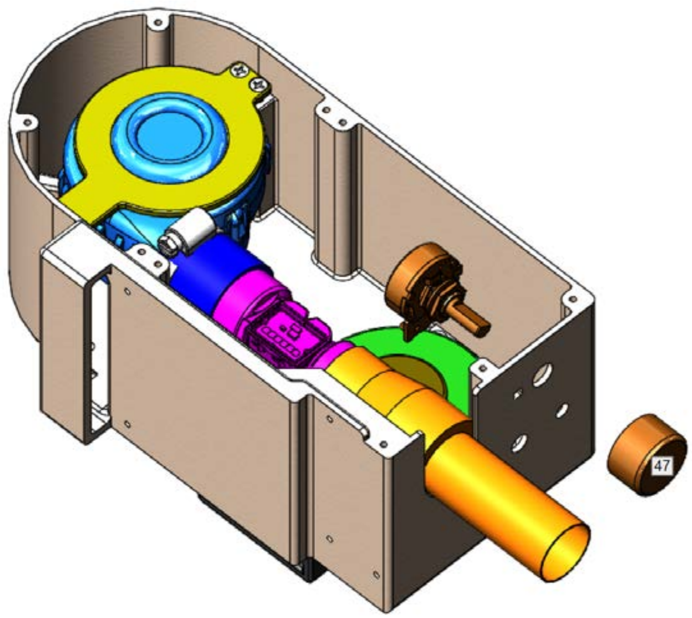


*Figure 61: ebmpapst potentiometer attachment*

11. Solder all electronic items, per wiring diagram in Figure 63.
    11.1. White wire from the blower controller should be folded back, and covered with electrical tape. It is not connected to anything

| Item No | Parts List Description | QTY |
|---|---|---|
| 21 | Electronics Lid, ebmPapst Blower | 1 |
| 33 | Thread-Forming Screws for Thin Plastic, M2 Size, 6 mm Long | 4 |
| 35 | Power Switch (2 state toggle switch) | 1 |
| 36 | Arduino Nano (Controller for alarm system) | 1 |
| 37 | Voltage regulator for Arduino | 1 |
| 38 | LED for alarm system | 1 |
| 39 | Resistor for LED pull up | 1 |
| 40 | Prototype Board | 1 |
| 41 | Buzzer | 1 |
| 42 | 1/8" x 4" Zip Ties | 1 |
| 43 | Jumper wires for various electronics | 1 |
| 44 | Inline Fuse Holder | 1 |
| 45 | 2 amp ATM mini blade fuse | 1 |
| 46 | Single Crimp Male Quick Disconnect Terminal | 1 |

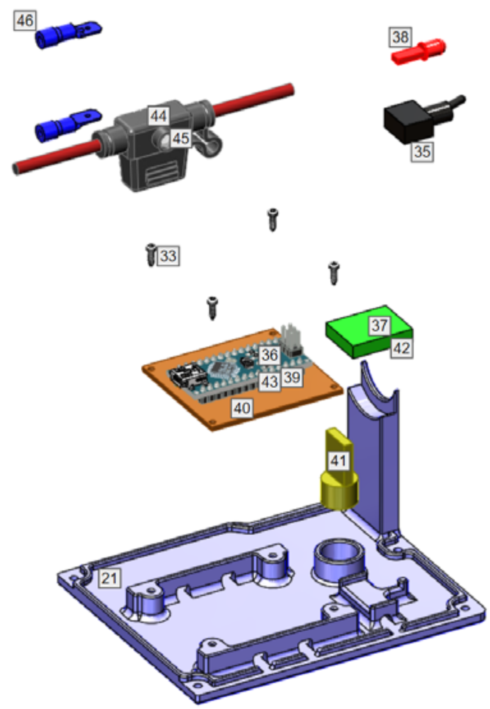


*Figure 62: Electronic Items to Solder*

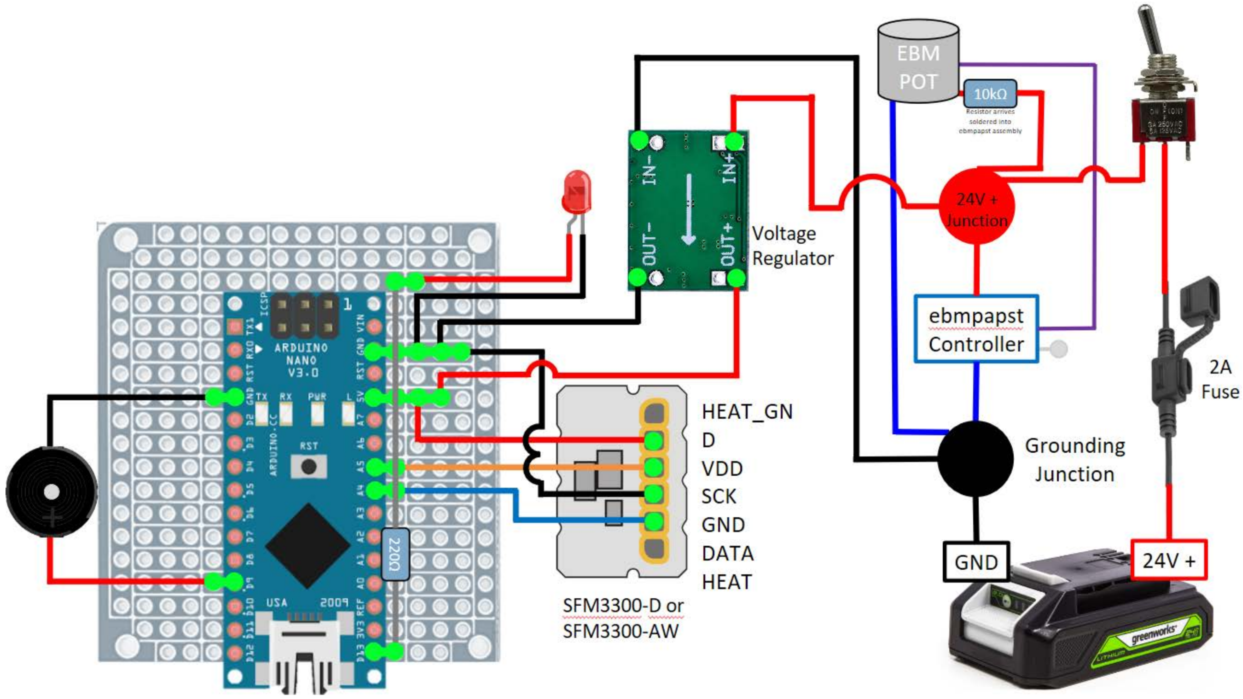


*Figure 63: ebmpapst Electronic Schematic*

12. More Electronics Assembly
    12.1. Connect the prototype board (40) with arduino (36) to the top lid. If M2 T6 screws (33) don't align, use slots for zip ties
    12.2. Affix Voltage Regulator for Arduino (37) to lid with zip tie
    12.3. Insert Buzzer (41) in slot as pictured, use hot glue to keep it in place

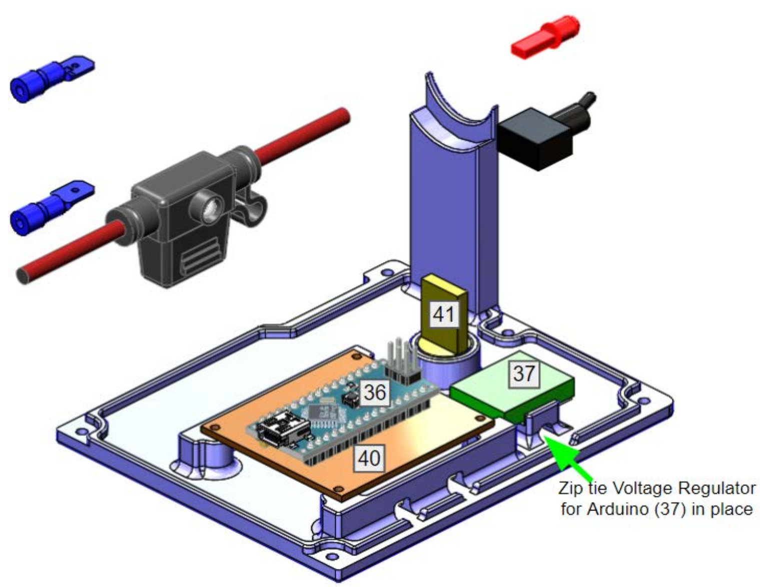


*Figure 64: Electronics Assembly*

13. Place switch, LED, and fuse in housing
    13.1. Remove nut and washer from Power Switch (35).
    13.2. Slide Power Switch (35) into Housing (17), as pictured.
    13.3. Reattach nut and washer to Power Switch (35), on outside of housing (17)
    13.4. Attach LED light (38) in Housing (17), secure with hot glue
    Note: May need to temporarily remove potentiometer for access
    13.5. Insert 2 Amp fuse (45) into Fuse Holder (44)
    13.6. Tuck Fuse Holder (44) to side, next to Flow Meter (34)

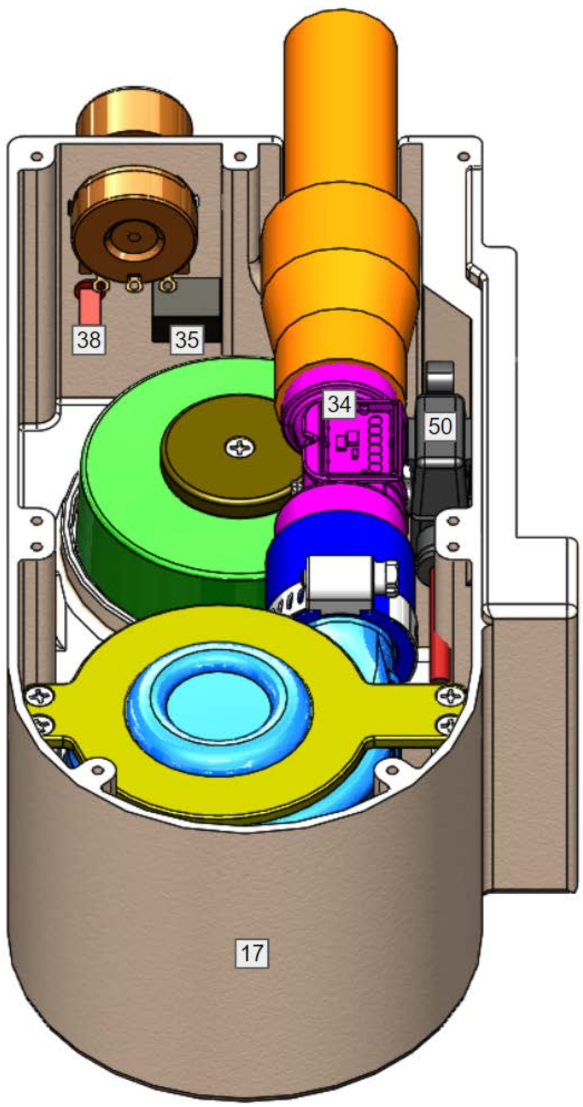


*Figure 65: Switch, LED, and Fuse Placement in Housing*

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14. Route Power Supply Wires to Exterior of Housing
    14.1. Route Quick Disconnect Terminals (46) through slot on side of housing (17)

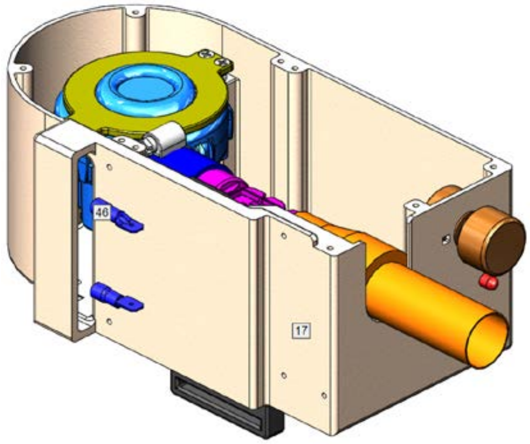


*Figure 66: Routing Power Supply Wires to External Housing*

15. Attach Lid to Housing
    15.1. Carefully place Electronics Lid (21) onto Blower Housing (17)
        15.1.1. Carefully wrap wires inside housing
        15.1.2. Ensure no wires are pinched
        15.1.3. Ensure no wires are pulled or connections are disconnected
        15.1.4. Verify Quick Disconnect Terminals (46) still remain on exterior of Housing (17)
    15.2. Use 5 screws (11) to affix Lid (21) to Housing (17)

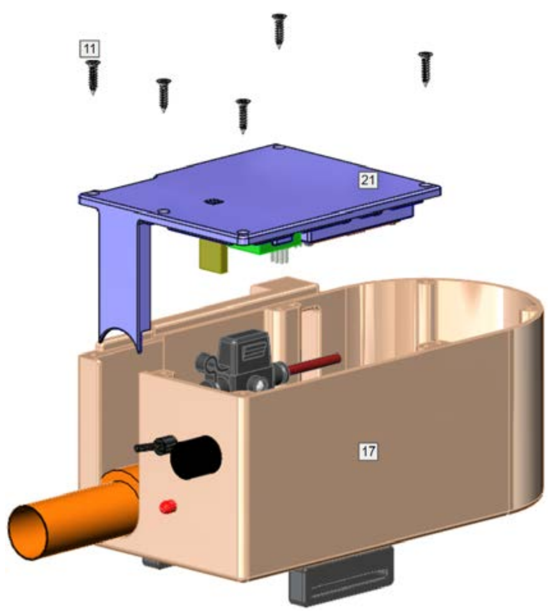


*Figure 67: Electronics Lid Attachment*

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16. Affix Battery Holder

16.1. Line up positive and negative Quick Disconnect Terminals (46) in Battery Holder (22) slots, so they align with positive and negative sides of the battery. Negative should be on the bottom.

16.1.1. Use a sharpie to denote on Battery Holder (22), which side is positive and negative

16.2. Use screws (11) to affix Battery Holder (22) to Housing (17).

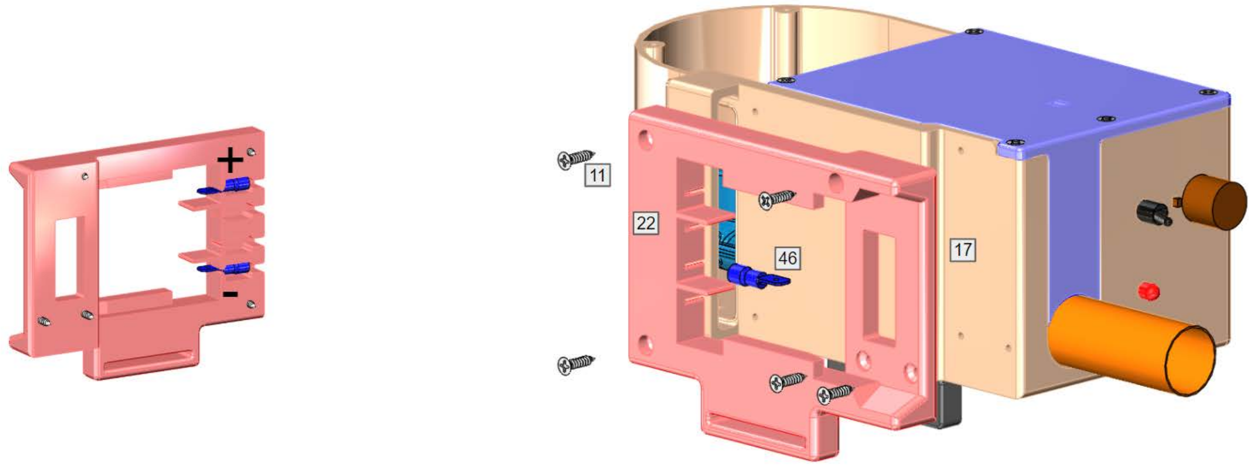


*Figure 68: Battery Holder Attachment*

17. Attach Blower Lid

17.1. Use 4 screws (11) to attach Blower Lid (22) to Housing (21).
- Again be careful packaging any wires

17.2. Place round foam seal (5) over filter interface on the Blower Lid (22)

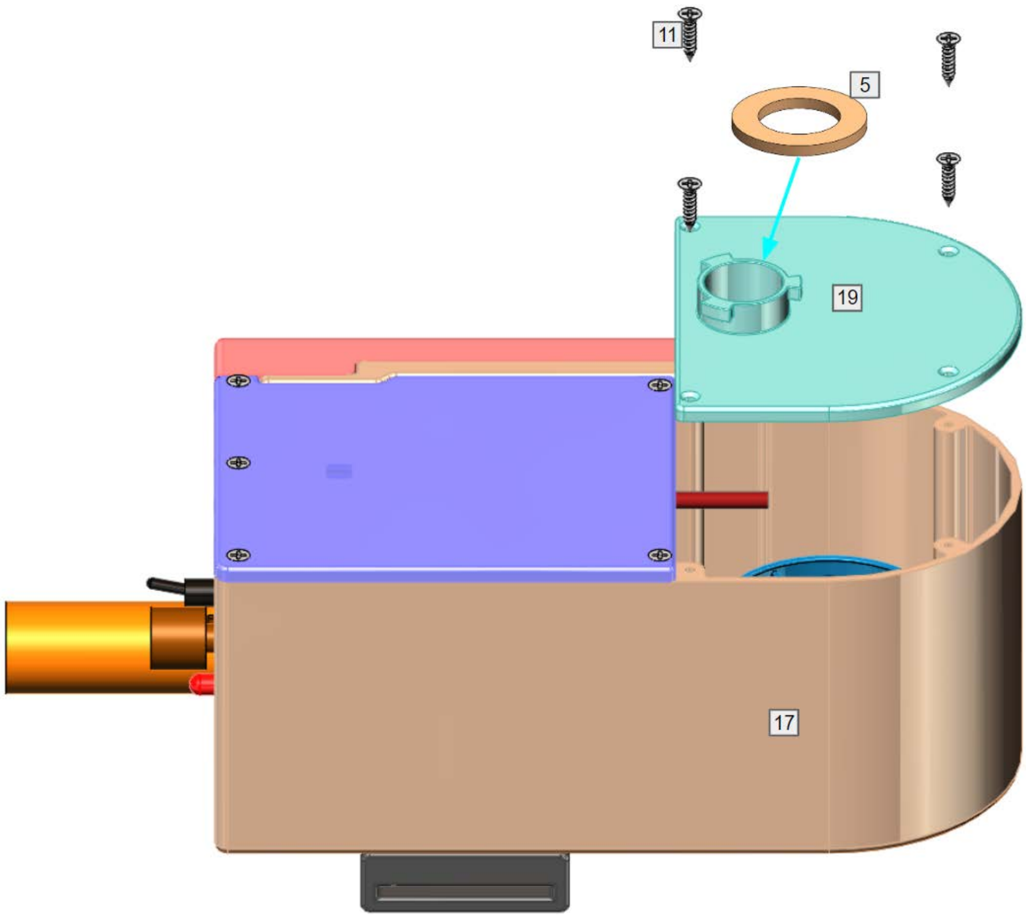


*Figure 69: Blower Lid Attachment*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

18. Attach the Inlet Filter Assembly (15180123) to the Blower Assembly
    18.1. Verify foam seal is installed in Inlet Filter Assembly (5)
    18.2. Affix Inlet Filter Assembly (15180123)
        - Check clocking slots to align correctly

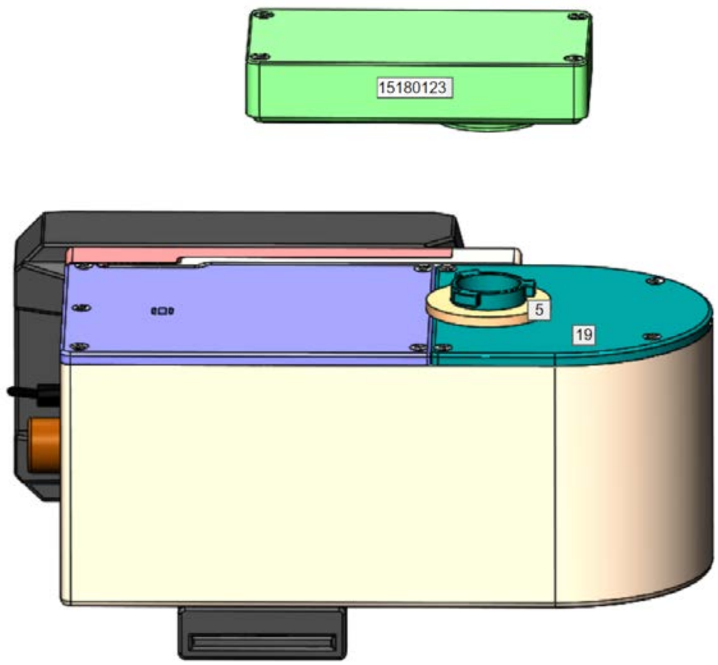


*Figure 70: Inlet Filter Attachment*

19. Ensure Power Switch (35) is in off position

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20. Slide Battery (12) into Battery Holder (22)
    20.1. Verify battery is fully charged
    20.2. Verify positive/negative leads line up correctly with battery

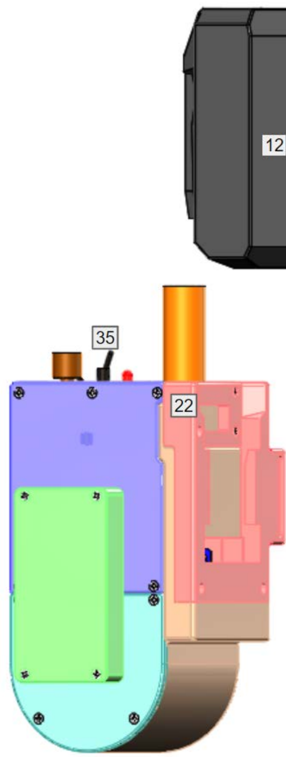


*Figure 71: Attach Battery to Blower Assembly*

21. Completed Blower Assembly

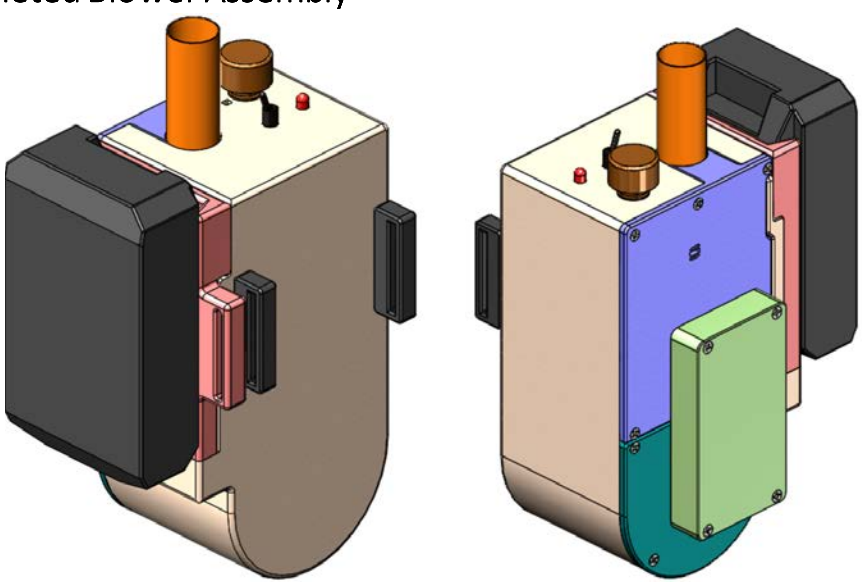

*Figure 72: Completed Blower Assembly*

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# Powered Air Purifying Respirator Assembly (15180125-1 and -2)

| | QTY -1 | QTY -2 | ITEM NO | PART NO | PART NOMENCLATURE | MATERIAL OR NOTE | MANUFACTURER |
|---|---|---|---|---|---|---|---|
| **105108125 Powered Air Purifying Respirator Assembly** | 1 | 1 | 1 | Seaview 180 V2 | Snorkel Mask | | Wildhorn Outfitters |
| | 1 | 1 | 2 | P09 | Tactical Belt | | Amazon / Fairwin |
| | | 1 | 3 | 15180124-2 | Blower Assembly | ABS | JPL Assembly |
| | 1 | | 4 | 15180124-1 | Blower Assembly | ABS | JPL Assembly |
| | 2 | 2 | 5 | 15180119-1 | Seal, Round, Filter Adapter | Multipurpose Neoprene Foam Strip | JPL Part |
| | 1 | 1 | 6 | 15180122-1 | Filter Assembly | ABS | JPL Assembly |
| | 1 | 1 | 7 | 15180109-1 | Hose Adapter | ABS | 3D Printed Component |
| | 1 | 1 | 8 | 15180112-1 | SeaView 180 V2 Snorkel Mask Side Adapter | ABS | 3D Printed Component |

*Table 10: 15180125-1 and -2 BOM*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

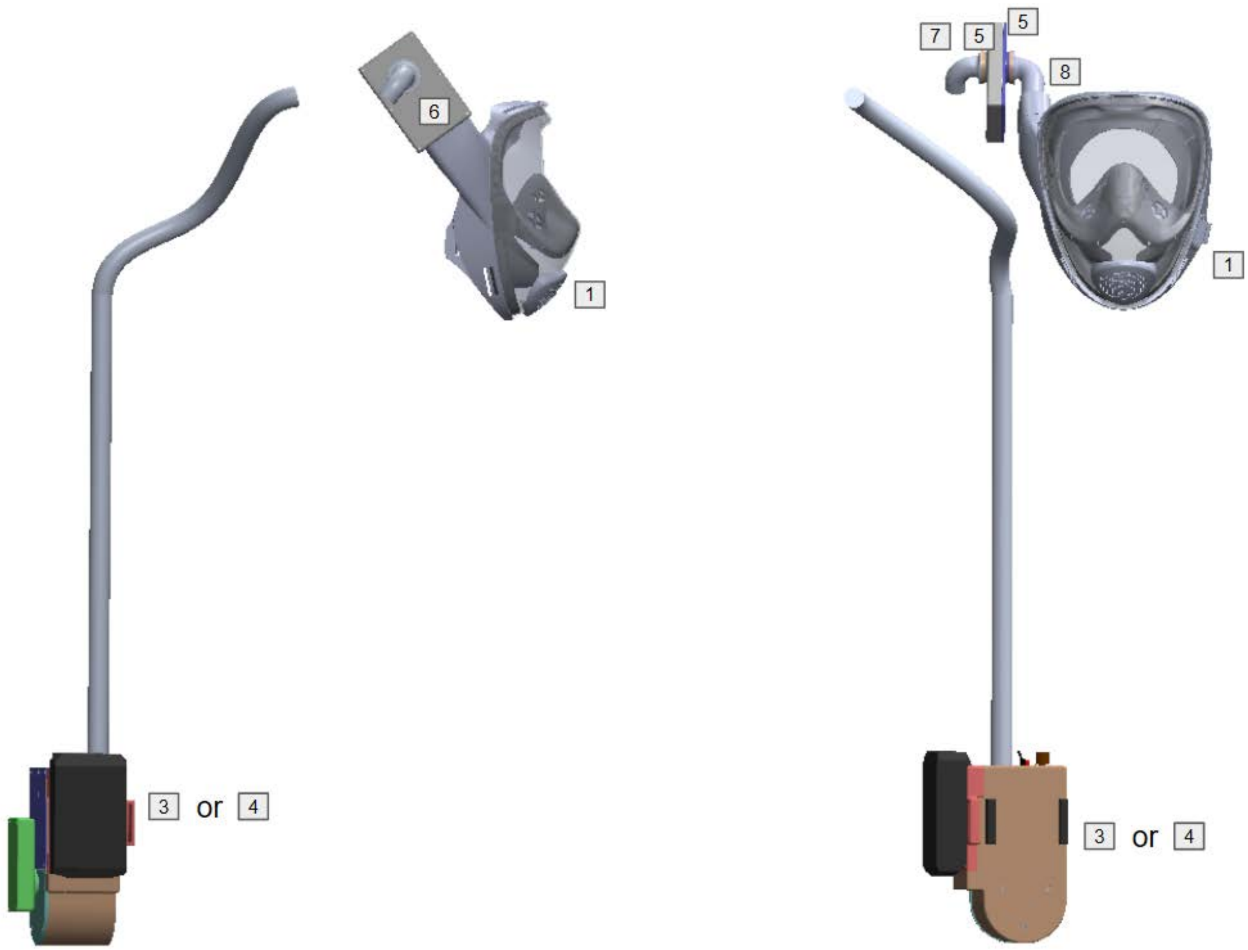


*Figure 73: Blower Assembly, Snorkel Mask & Filter Assembly w/ Adapters*

1. **Layout all the 15180125-1 or -2 components**

2. **Assemble Snorkel Mask Adapter / Filter Assembly**
   2.1. Assemble round foam seals (5) to the Hose Adapter (7) and the SeaView 180 V2 Snorkel Mask Adapter (8) interfaces
   2.2. Assemble Hose Adapter (7), the Filter Assembly (6), and the SeaView 180 V2 Snorkel Mask Adapter (8) as shown.

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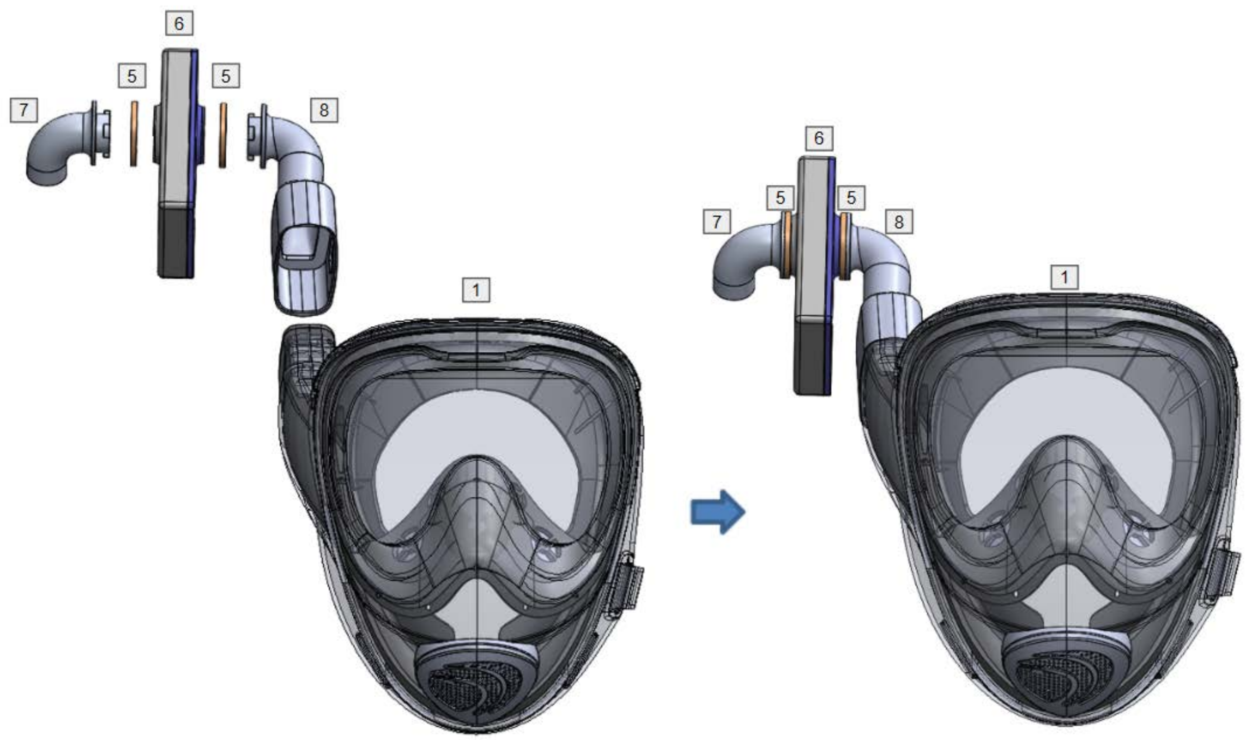


*Figure 74: Snorkel Mask and Filter Assembly With Adapters*

3. **Blower Assembly and Mask Attachment**
    3.1. Attach the CPAP Hose from the Blower Assembly (3 or 4) to the Hose Adapter (7) that is attached to the Snorkel Mask

4. **Attach Belt**
    4.1. Thread Belt (2) through Belt Attachment (23)

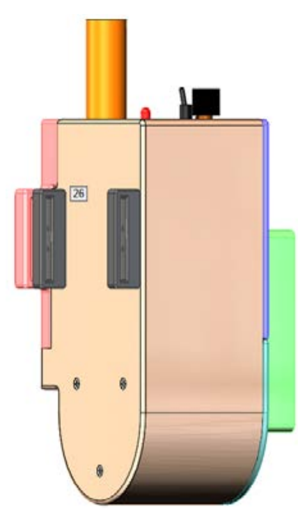


*Figure 75: Belt Attachment*

## 5. **Don the PAPR Assembly (Belt and Mask)**

*Figure 76: PAPR System on User*

*Figure 77: Fully Assembled PAPR System*

# JPL PAPR Operating Instructions

## A. Preparation and Caveats for PAPR Use

The following information is provided for the potential user, especially if this PAPR unit is to be utilized in a pathogen aerosol environment such as COVID-19. Strict protocols are typically utilized in hospital settings and some of these are listed here to educate anyone who may wish to build and use this device. This section is provided in order to strongly caution the potential user that it is critical to follow the steps and protocols in order to safely operate this PAPR device. The information in this section is excerpted directly from Reference 2, **OSHA 3767, Respiratory Protection: NIOSH/OSHA/CDC Hospital Respiratory Protection Program Toolkit**. Healthcare professionals are expected to be proficient in the use and maintenance of a PAPR device, however, for the novice user it is strongly encouraged to read this reference prior to engaging patients in any COVID-19 environment.

PAPR Fit Test

First and foremost, a proper fit of the Wildhorn Outfitters® Snorkel Mask is required for safe operation of the PAPR device. The Wildhorn Outfitters®, V2 Seaview 180 mask is provided in three sizes, small, medium and large. The user must properly select the appropriate size for the planned application. From Reference 2, "The fit test ensures that, when donned properly, the selected brand and size of respirator fits adequately to protect the wearer from excessive inward leakage of contaminant through the face seal." Wildhorn Outfitters® has performed the NIOSH required fit checks ( 42 CFR, Part 84, 176(b)) for a general subject and it passed accordingly (see Test and Results Section, Test #1).

Summary of Fit Test Requirements

The following requirements are provided directly from Reference 2.

• All personnel required to wear tight fitting respirators must be fit tested after receiving medical clearance, prior to respirator use, and annually thereafter.

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• An OSHA-accepted fit test protocol must be followed exactly as it is written in the standard. This may be a qualitative test using Bitrex® or saccharin, or a quantitative test using a condensation nuclei counter or another appropriate instrument. (See Fit Check Test #1, Wildhorn Outfitters®)

• Fit testing must be performed by an individual knowledgeable in respiratory protection, and qualified to follow the protocol and train the employee to properly put on and take off the respirator.

• Records of fit tests must be kept on file until the next annual test is performed, and you must make sure that employees use only the respirator model and size for which they have passed a fit test.

• There is no fit test requirement for PAPRs with loose-fitting facepieces, hoods, or helmets. **A PAPR with a tight-fitting facepiece requires fit testing (with the blower off).**

PAPR Donning and Doffing

It is important for safety reasons to properly don the PAPR unit so that it works safely and protects the user from pathogens and other aerosols. Likewise, it is even more important to properly doff the unit so as not to contaminate or cause the user to come into contact with pathogens during the unit removal. There are many videos that are offered on Youtube which describe these general procedures. Some of these videos are linked in Reference 3 for the potential user to view as necessary. Most healthcare professionals are proficient with these procedures, but again, for the novice user, it is highly encouraged to review this material prior to entering or exiting a hazardous environment. Some of the procedural steps are listed below but there are many more details in the videos that cannot be adequately listed.

Summary of Donning Requirements

A. All ancillary PPE should be donned prior to donning the PAPR Unit including Gowns, booties/boots and gloves per local protocol.

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B. Remove PAPR Unit from storage location, inspect battery condition and charge state. Perform air flow test with unit on bench to ensure proper operation.

C. Attach blower assembly to subject's waist using tactical belt and switch PAPR power to the "On" position.

D. Connect Blower Assembly Hose to Snorkel Mask Adapter & Filter assembly.

E. Install Snorkel Mask and ensure adequate fit. Mask should seal to the user's face with a minimum of leaks. Note: Because the PAPR provides a positive pressure a leak tight seal is not required.

Summary of Doffing Requirements

A. Remove gloves and don a new pair of clean gloves.

B. Wipe the exterior surfaces of the facepiece / mask with disinfectant dampened wipes.

C. Remove gloves and carefully remove the mask/facepiece, leaving the PAPR unit running.

D. Don a new pair of gloves and with the PAPR unit running, thoroughly wipe outside of the facepiece/mask with disinfectant dampened wipe.

E. Remove the blower assembly and wipe down the exterior surfaces of the blower assembly, hose and belt.

F. With the PAPR unit running, wipe the interior surfaces of the facepiece/mask. The running unit will assist with drying of the interior surfaces.

G. When thoroughly dry, switch the unit to the off position, remove and charge the battery and carefully store the PAPR system in a clean environment for the next use.

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# B. Operation

Operating the JPL PAPR unit is a very simple procedure. First, ensure that the battery is charged and insert it into the side of the blower assembly, feeling and listening for the “click”. Don the unit safely per the instructions listed above. As an overview, there is a single ON-OFF toggle switch, an Adjustment Knob for the motor speed and blower flow rate and a single LED lamp for visual feedback. A graphic of the blower assembly is shown below.

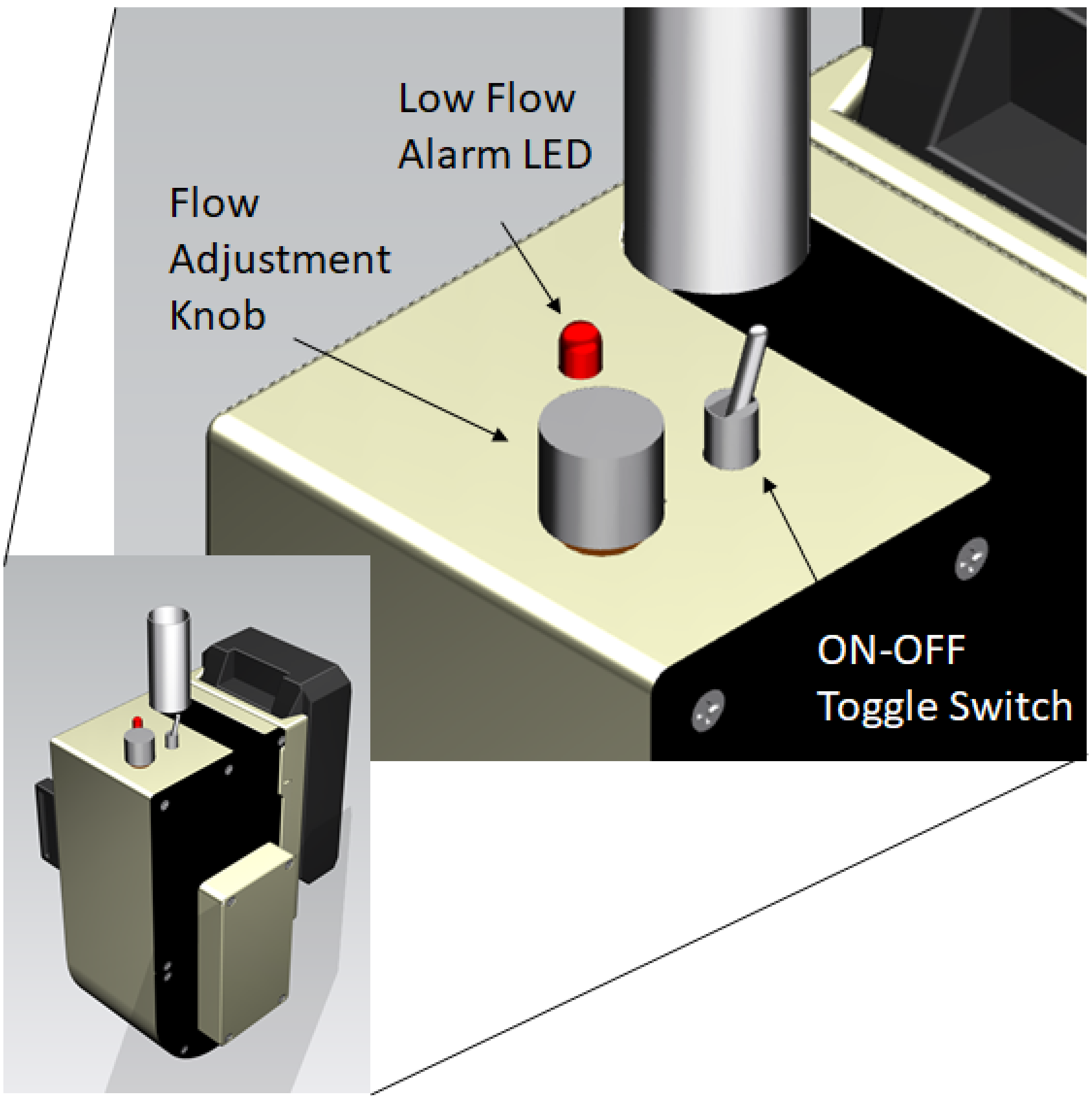


*Figure 78: Blower Assembly: ON-OFF Switch, Air Flow Adjustment Knob and LED*

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Turning On Unit

For operation, simply toggle the switch to the ON position. The LED lamp will light up indicating power to the unit and a brief audible alarm will sound.

Adjusting Air Flow

For flow adjustment, turn the adjustment knob in the clockwise direction and adjust the flow to a comfortable environment.

Turning Off Unit

To switch the unit off, toggle the switch to the “OFF” position.

Low Flow Rate Alarm System

The JPL PAPR unit is equipped with a low flow rate alarm system per 42 CFR 84 requirements. Should the flow rate drop below 4 CFM (115 lpm), which is prescribed as the minimum flow rate for a tight fitting respirator facepiece, then an audible alarm will sound, and the LED lamp will light, alerting the user. Adjustment of the flow rate is provided by turning the Flow Adjustment Knob in the clockwise direction as described earlier. A photo of the unit operation is provided below. Visit [https://github.com/nasa-jpl/COVID-19-PAPR] for a video covering the operation of the PAPR.

*Photo of the JPL PAPR Low Flow Alarm LED in Operation*

## C. Maintenance and Cleaning

The following procedures are excerpted directly from Appendix D of Reference 2, Hospital Respiratory Protection Program Toolkit, OSHA Document 3767. It is recommended that between use, the cleaning procedures are exercised carefully and thoroughly.

General Procedures for Cleaning Respirators

A. Remove filters, cartridges, or canisters. Disassemble facepieces by removing speaking diaphragms, demand and pressure-demand valve assemblies, hoses, or any components recommended by the manufacturer. Discard or repair any defective parts.

B. Wash components in warm (43 deg. C [110 deg. F] maximum) water with a mild detergent or with a cleaner recommended by the manufacturer. A stiff bristle (not wire) brush may be used to facilitate the removal of dirt.

C. Rinse components thoroughly in clean, warm (43 deg. C [110 deg. F] maximum), preferably running water. Drain.

D. When the cleaner used does not contain a disinfecting agent, respirator components should be immersed for two minutes in one of the following:

> 1. Hypochlorite solution (50 ppm of chlorine) made by adding approximately one milliliter of laundry bleach to one liter of water at 43 deg. C (110 deg. F); or,
> 2. Aqueous solution of iodine (50 ppm iodine) made by adding approximately 0.8 milliliters of tincture of iodine (6-8 grams ammonium and/or potassium iodide/100 cc of 45% alcohol) to one liter of water at 43 deg. C (110 deg. F); or,
>
> 3. Other commercially available cleansers of equivalent disinfectant quality when used as directed, if their use is recommended or approved by the respirator manufacturer.

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E. Rinse components thoroughly in clean, warm (43 deg. C [110 deg. F] maximum), preferably running water. Drain. The importance of thorough rinsing cannot be overemphasized. Detergents or disinfectants that dry on facepieces may result in dermatitis. In addition, some disinfectants may cause deterioration of rubber or corrosion of metal parts if not completely removed.

F. Components should be hand-dried with a clean lint-free cloth or air-dried.

G. Reassemble facepiece, replacing filters, cartridges, and canisters where necessary.

H. Test the respirator to ensure that all components work properly.

General Maintenance of Filter Elements

There is no prescriptive time interval for replacement of the filters or filter elements. Replacement time intervals will depend on the environment in which the unit will be operated and the total duration of operation in this environment.

In general, a filter should be replaced for the following reasons:

1) The unit fails the airflow test described in the Donning Procedure or a user may find, over the course of time, that the Flow Adjustment Knob is running out of “headroom”, ie. the filter is loaded such that the airflow is severely impacted.
2) The motor is notably working harder (and louder) for the equivalent flow rates.

If any of the conditions is realized, it may be time to swap out the filter material for new HEPA material per the Filter Assembly instructions provided. Be sure to use the proper precautions in handling the used filter material and properly dispose of it accordingly.

# Future Work / Needed Improvements

Due to the accelerated timeline of the project, JPL engineers had limited time to iterate on the design and were unable to produce a polished product. This PAPR design should be considered as a starting point and can serve as a foundation for further development. Listed below are some identified areas of improvement for this JPL design. The suggestions fall into two general categories: 1) Design Improvements and 2) Design Enhancements. The former category describes areas of the design that were deemed deficient or could use some further development to improve function. The latter category describes some areas of design exploration that could lead to a better overall and perhaps a more desirable product.

### Design Improvements

- Filter Media Replacement: A modular design with snaps, instead of fasteners, on the filter casing to make it easier to replace the filters.
- Assembly Improvement: Use of a PCB board, instead of soldering wires for easier assembly.
- CPAP Hose Release: A design that does not trap the hose fitting inside the Blower Assembly to aid in removal for cleaning.
- Positive Hose Locks / Attachments: A ribbed or lip feature on the Mask Adapter to prevent the hose from slipping off of the fitting.
- Positive Filter Locks / Attachments: A feature over and above friction to ensure a positive lock on the filter casing to the Blower and to the Mask / Hose adapters.

### Design Enhancements

- PAPR Soft Hood: Exploration of a configuration that employs a hood instead of a rigid facepiece.
    - Several companies were discovered in the design process that initiated development and produced soft hoods for a PAPR application. ILC Dover in Delaware and Superfeet in Ferndale, Washington are two such companies.
    - Implementation of this configuration would require some additional hose interfaces for the soft hood. It would also require a higher

nominal flow rate, a minimum of the 170 lpm and adjustment of the arduino controller low flow alarm set point.

- Persistence Alarm: 30 second persistence alarm for low flow alarm, so minor fluctuations of flow do not trip the alarm unnecessarily.

# Resources and References

1) Title 42, Public Health, Code of Federal Regulations, Part 84; Approval of Respiratory Devices.

2) OSHA 3767; Hospital Respiratory Protection Program Toolkit; Resources for Respirator Program Administrators; May 2015, **Respiratory Protection: NIOSH/OSHA/CDC Hospital Respiratory Protection Program Toolkit**

3) Some examples of Proper Donning & Doffing PAPR Units: https://www.youtube.com/watch?v=2rdeBq_hznI

4) https://www.cdc.gov/niosh/npptl/respstandards/papr.html

5) https://www.federalregister.gov/documents/2020/04/14/2020-07804/approval-tests-and-standards-for-air-purifying-particulate-respirators

# Disclaimer

The designs herein have not been reviewed, cleared, or approved by FDA or other regulatory authority, nor have they received Coronavirus Disease 2019 (COVID-19) Emergency Use Authorizations for Medical Devices. Neither California Institute of Technology (including the Jet Propulsion Laboratory) ("Caltech") nor its employees or agents provide any representation or warranty, express or implied, for fitness for a particular purpose, safety, efficacy, or non-infringement of any third party intellectual property rights. Caltech offers these device designs in good faith to help healthcare providers and others prevent the spread of and treat patients with COVID-19. Physicians and other healthcare providers bear full responsibility to convey warnings and obtain patients' informed consent.

# Acknowledgement

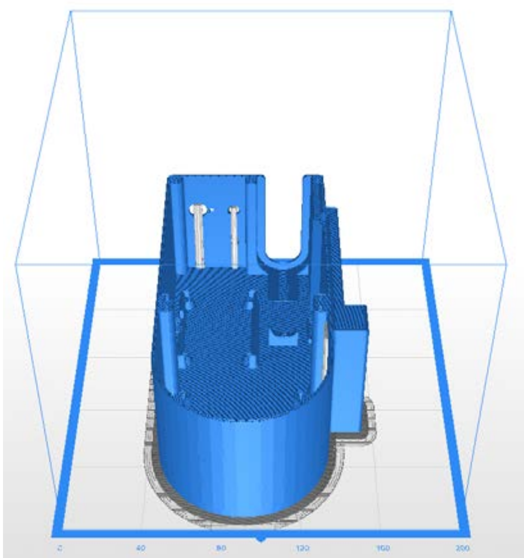
The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

A special thanks to Globe Tools, greenworks, ebmpapst, Sensirion and Wildhorn Outfitters for the all of the support on this NASA Jet Propulsion Laboratory COVID-19 PAPR development effort. Their hardware, technical, manufacturing, and sales support was instrumental in the success of this project.

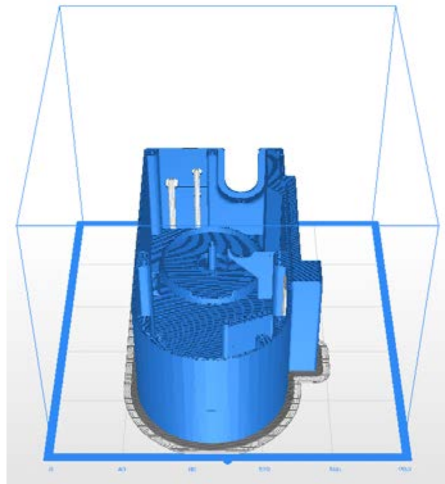
# APPENDIX A – 3D Printed Components Print Strategies

The following pages in this Appendix describes possible print strategies for each individual 3D printed part. These strategies contain information on part orientation and support structure generation. All 3D printed components should be oriented as shown in the images below. Most softwares will automatically generate the necessary support material for the build.

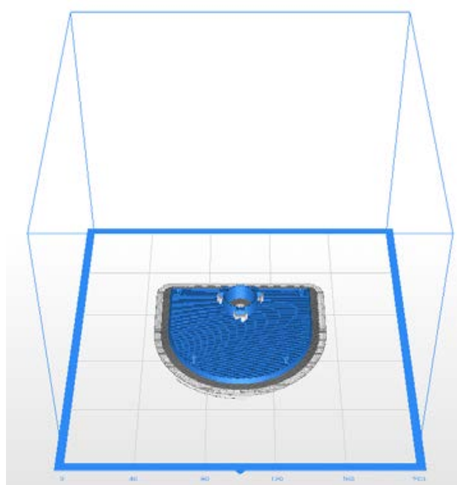
In addition, **all 3D printed components should be printed with an infill of at least 50%**. Note, a lower percentage infill leads to less structural integrity with a short build time, and a higher infill percentage leads to greater structural integrity with a longer build time. The takeaway is that customizing the infill percentage has negative and positive implications pertaining to print time and structural integrity.



| Housing, Globe Tools Blower, 15180101-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 90 | 0 | 0 |



| Housing, ebmpapst Blower, 15180101-2 | | |
|---|---|---|
| Rotation X, degrees | Rotation Y, degrees | Rotation Z, degrees |
| 90 | 0 | 0 |



| Blower Lid, Universal Blower, 15180102-1 | | |
|---|---|---|
| Rotation X, degrees | Rotation Y, degrees | Rotation Z, degrees |
| 90 | 0 | 0 |

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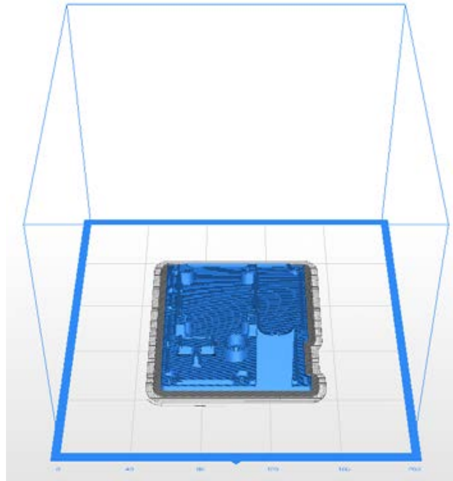
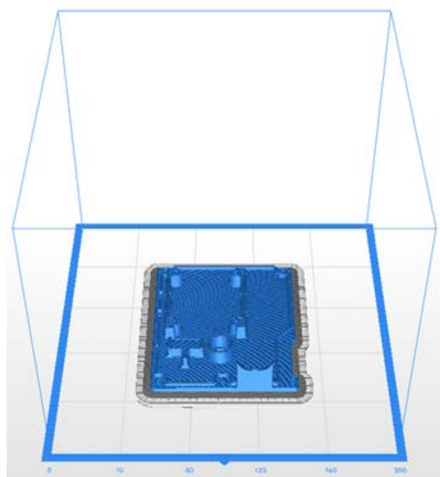
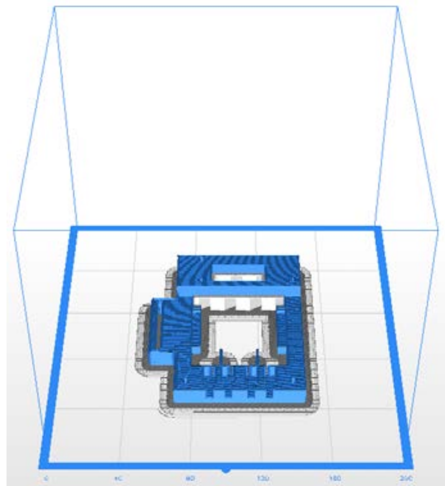


| Electronics Lid, Globe Tools Blower, 15180103-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 270 | 0 | 0 |

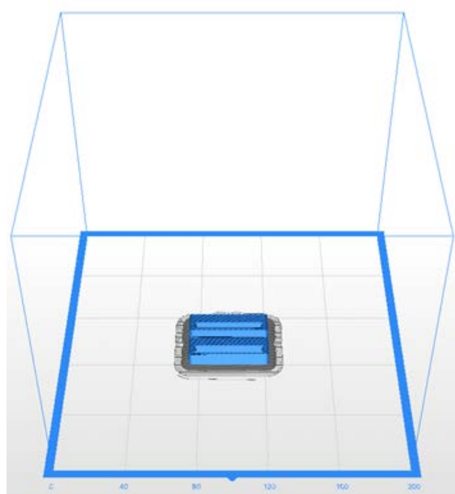


| Electronics Lid, ebmpapst Blower, 15180103-2 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 270 | 0 | 0 |

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration



| Battery Holder, Universal Blower, 15180104-1 | | |
|---|---|---|
| Rotation X, degrees | Rotation Y, degrees | Rotation Z, degrees |
| 270 | 0 | 0 |



| Belt Attachment, Universal Blower, 15180105-1 | | |
|---|---|---|
| Rotation X, degrees | Rotation Y, degrees | Rotation Z, degrees |
| 0 | 90 | 0 |

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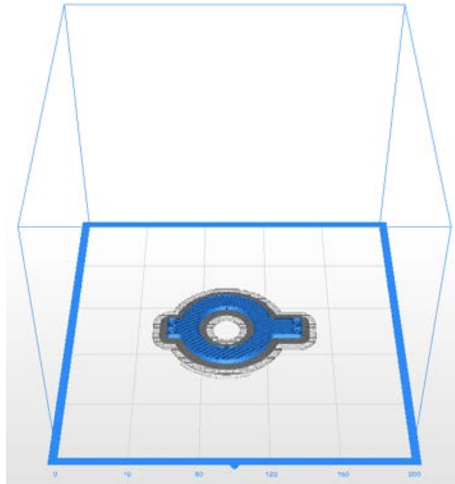
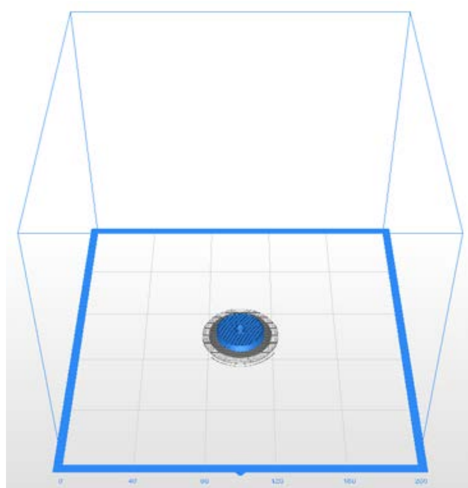


| Blower Mount, ebmpapst Blower, 15180107-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 270 | 0 | 0 |



| Controller Mount, ebmpapst Blower, 15180108-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 90 | 0 | 0 |

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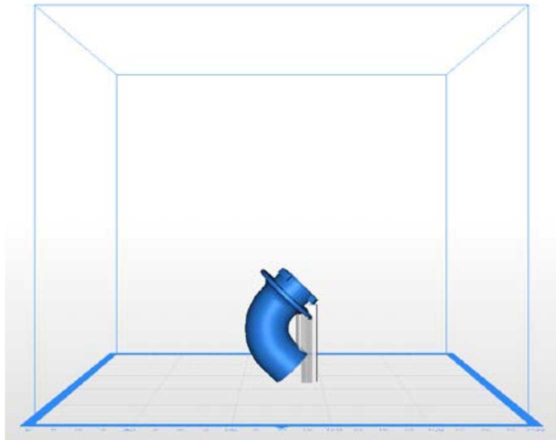
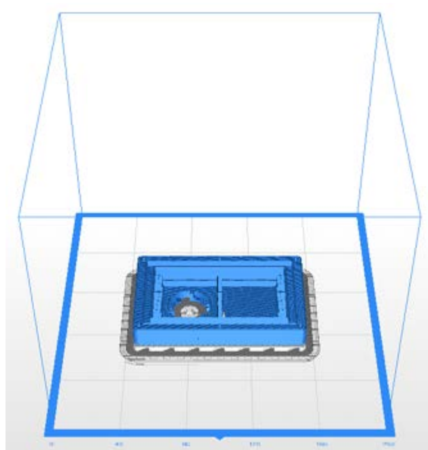


**Note**: No support material is inside the tube in this orientation.

| Hose Adapter, 15180109-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 0 | 0 | 0 |



| Helmet Filter Base (Sealed 3m), 15180110-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 90 | 0 | 0 |

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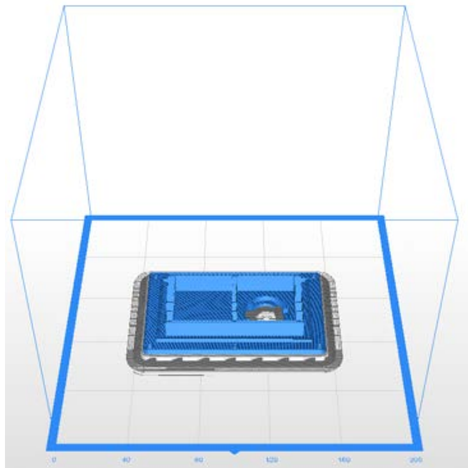
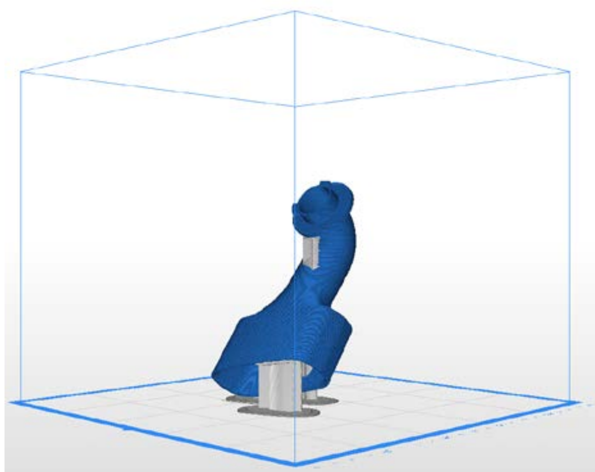


| Helmet Filter Cover (Sealed 3m), 15180111-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 270 | 0 | 0 |



**Note**: No support material is inside the tube in this orientation.

| Seaview 180 V2 Snorkel Mask Side Adapter, 15180112-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 0 | 0 | 0 |

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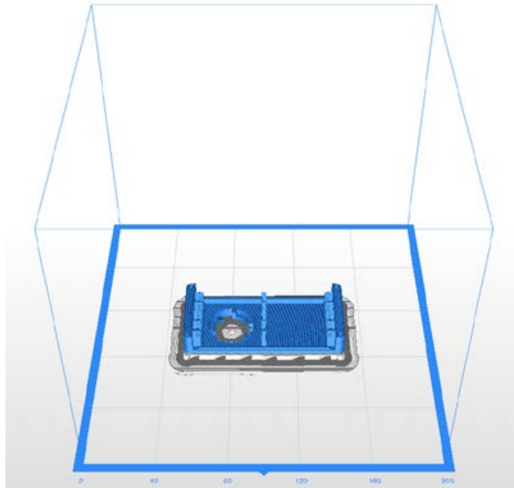
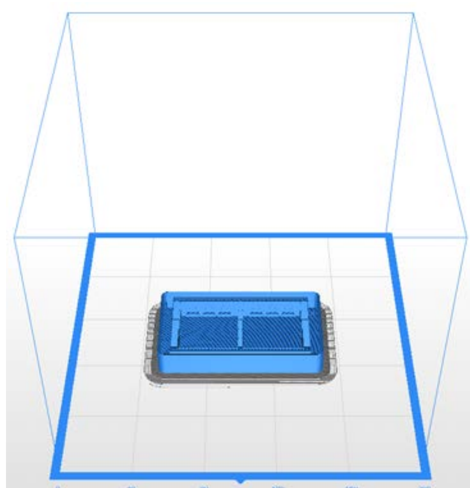


| Inlet Filter Base, 15180113-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 90 | 0 | 0 |



| Inlet Filter Cover, 15180114-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 270 | 0 | 0 |

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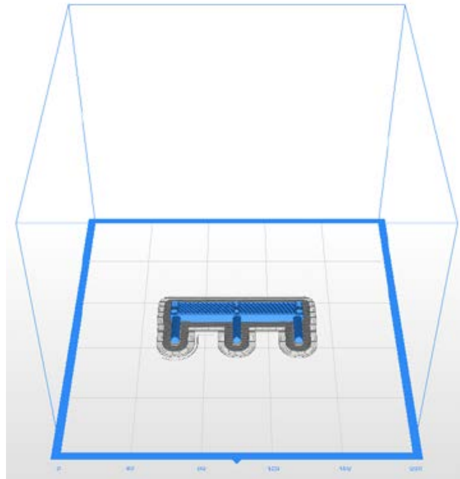
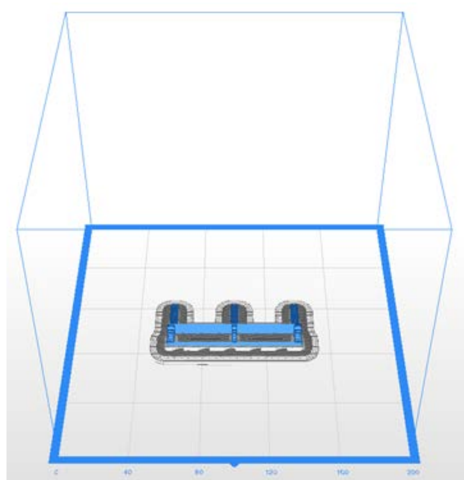


| Filter Tool 1, 15180115-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 180 | 0 | 0 |



| Filter Tool 2, 15180116-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 0 | 0 | 0 |

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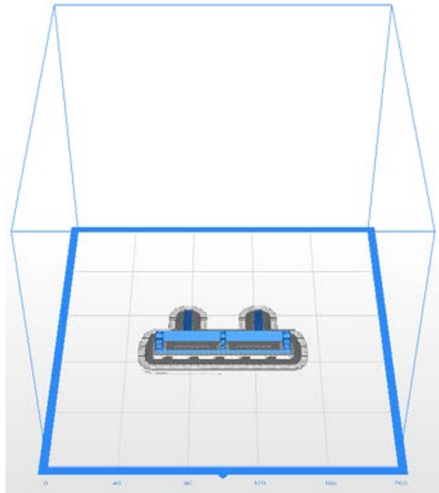

| Filter Tool 3, 15180117-1 | | |
|---|---|---|
| **Rotation X, degrees** | **Rotation Y, degrees** | **Rotation Z, degrees** |
| 0 | 0 | 0 |

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# APPENDIX B – Commercial Off-the-Shelf Component Detailed Information

The following sections provide some detailed information relative to the Commercial-Off-the-Shelf components that are used in the JPL designed PAPR Assembly. As a reminder, the detailed Bill Of Materials (BOM) contains URL links to supplier's websites where more technical information and purchasing information can be found [https://github.com/nasa-jpl/COVID-19-PAPR].

**Wildhorn Outfitters Snorkel Mask, Seaview 180 V2:**


Wildhorn Outfitters Snorkel Mask, Seaview 180 V2 sells masks in sizes small, medium, and large.

**Globe Tools - 24VDC Blower Motor Assembly:**

Blower Features:

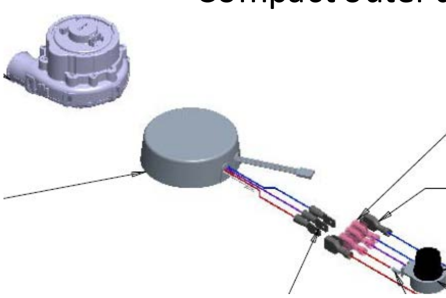
- Noise level of 83 dB(A)
- Dynamic performance: 34,000 rpm with static pressure increase of over 7,000 Pa
- Compact outer dimensions, and weighs 90 grams (3.2 oz)

- 

ebmpapst - 24VDC Blower Motor Assembly:

Blower Features:

- Noise level of 49 dB(A)
- Dynamic performance: 39,000 rpm with static pressure increase of over 5,000 Pa
- Compact outer dimensions and weighs 135 grams (4.8 oz)



**Sensirion Flow Meter**

Used to measure flow rate provided to weareer, and serve as input into the low flow alarm system.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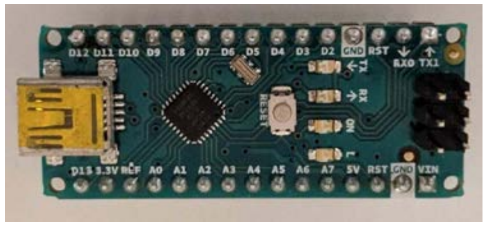
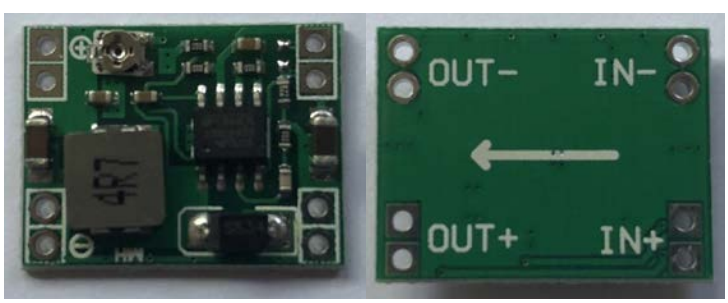
**Arduino Controller Board and Components:**



Arduino Nano Board available in the tens of thousands from online suppliers.

Piezo Buzzer Speaker available in the tens of thousand from online suppliers.

Red LED available in the tens of thousands from electronics suppliers.




Step Down Voltage Regulator available in the tens of thousands from online suppliers.

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**CPAP Supply USA - CPAP Hose:**

4 Foot Length of CPAP Hose, purchased from CPAP Supply USA. This supplier has a significant stock of this material.

**greenworks - Lithium-Ion Battery and Charger:**

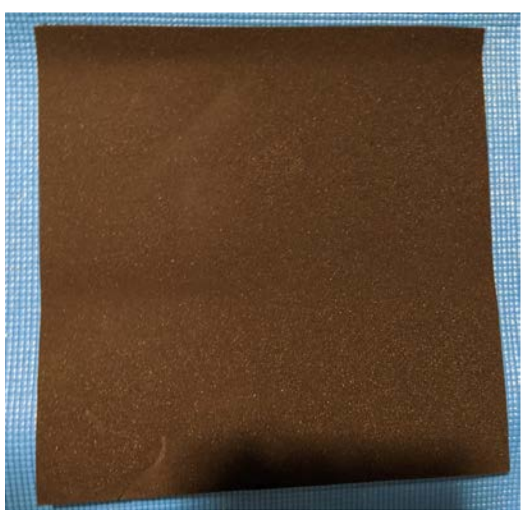


2AH, 24V battery & battery charger, purchased from Greenworks, this supplier has a significant stock of this material. Greenworks also has a 4 AH battery available, if longer duration usage of PAPR is required.

**Filter Material:**


Hepa Vacuum Bag, can be purchased from Amazon or a local hardware store, there should be a significant stock of this item available for sale

**McMaster-Carr - Foam:**



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Multipurpose Neoprene Foam Strip, purchased from McMaster-Carr, there should be a significant stock of this item available for sale

**McMaster-Carr - Quick-Disconnect Terminal:**

Single Crimp Male Quick Disconnect Terminal, purchased from McMaster-Carr but also available at many auto stores, there should be a significant stock of this item available for sale

**McMaster-Carr - Fuse:**

Automotive Fuse, purchased from McMaster-Carr but also available at many auto stores, there should be a significant stock of this item available for sale

**Clear Tubing:**

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

Clear Tubing, sizes and suppliers are called out in the main BOM [which can be found here:https://github.com/nasa-jpl/COVID-19-PAPR], there should be a significant stock of this item available for sale

**McMaster-Carr - General Purpose Worm-Drive Clamps for Firm Hose and Tube:**

Worm-Drive Clamp, purchased from McMaster-Carr but also available at many auto stores, there should be a significant stock of this item available for sale

**Amazon - Power Switch:**

Power Switch, purchased from Amazon, there should be a significant stock of this item available for sale

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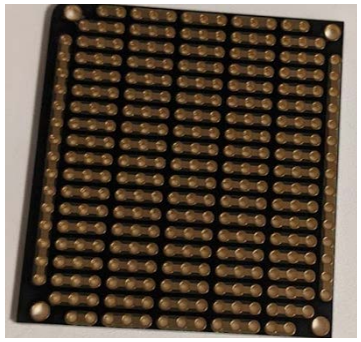
**Amazon - Prototype Board:**

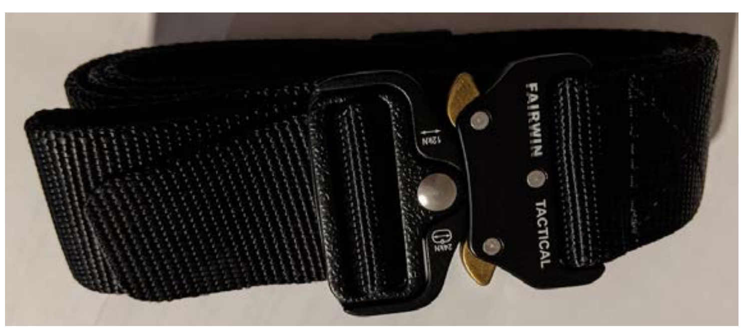


Prototype Board, purchased from Amazon, there should be a significant stock of this item available for sale

**McmasterCarr - Inline Fuse Holder:**

Inline Fuse Holder, purchased from McMaster-Carr but also available at many auto stores, there should be a significant stock of this item available for sale

**Amazon - Tactical Belt:**




Tactical Belt, purchased from Amazon, there should be a significant stock of this item available for sale. Any belt that fits through the belt loop slots, and can carry the weight of the PAPR is acceptable.

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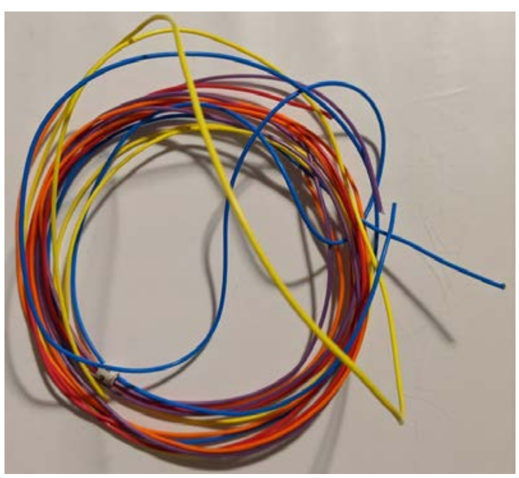
**McMaster-Carr - #4-1/2 in long C-Sink screws**

#4-1/2 in long C-Sink screws, purchased from McMaster-Carr but available at most hardware stores, there should be a significant stock of this item available for sale

**McMaster-Carr - M2 X 6 MM Long Thread Forming Screws for thin Plastic**

M2 X 6 MM Long Thread Forming Screws for thin Plastic, purchased from McMaster-Carr, there should be a significant stock of this item available for sale

**Amazon - Jumper Wires**



Jumper Wires, Purchased from Amazon but there also are many other suppliers to purchase these from, there should be a significant stock of this item available for sale

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

# APPENDIX C - Detailed Technical Specification

| Attribute | Technical Specification |
|---|---|
| Airflow | Nominal 4 CFM (115 Lpm)<br>Maximum 8.5 CFM (240 Lpm) |
| Alarm - Low Flowrate | Audio & Visual<br>• Activates when airflow falls below 4 CFM (115 Lpm)<br>• Alarm decibel level - 80.5 dBA measured at user's ear |
| Operating Altitude Range | Approximately sea level to 2600 feet (800 meters) |
| Assigned Protection Factor | 25, w/ Wildhorn Outfitters V2 Seaview Mask Facepiece (Note 1) |
| Breathing Tube Length | 48 inches (122 cm) |
| Decontamination | Does not meet Ingress Protection (IP) rating of IP-53 (EN 60529).<br>Disinfectant wipe or light spray only. |
| Dimensions – Motor/Blower Assembly | 7.3 in (18.5 cm) H x 5.6 in (14.2 cm) W x 4.7 in (12.0 cm) D |
| Weight<br>•Blower Unit, belt & specified battery<br><br>•Mask, w/ Filter & Adapters | <br>• 2.9 lbs (1330 gms) w/ greenworks 2Ah Battery<br>• 3.5 lbs (1588 gms) w/ greenworks 4Ah Battery<br>• 1.3 lbs (578 g) |
| Filtration | Custom filters using HEPA Grade Vacuum Bag materials; Exceeds N95 Filtration Rating (Not NIOSH Approved) |
| Materials<br>• PAPR Blower Assembly body<br>• Filter Assembly Housings & Adapters | <br>• Acrylonitrile Butadiene Styrene (ABS)<br>• Acrylonitrile Butadiene Styrene (ABS) |
| Noise Levels | Less than 80 dBA excluding external noise |
| Temperature Limits<br>• Intended Operating Environments<br>• Storage | <br>• 60º F to 95º F (15º to 35º C)<br>• Optimal 40º to 95º F (4º C to 35º C) (2) |
| Service Life - Motor/blower | ~5000 hours (estimated depending on use conditions) |
| Battery Pack<br>• Chemistry<br>• Service Life<br>• Storage temperature<br>• Weight - 2Ah / 4Ah<br>• Run time - 2Ah / 4Ah | greenworks 24 Volt Battery<br>• Lithium Ion<br>• 250 charge cycles<br>• Optimal 59º F (15º C).<br>• 0.96 lbs. (437 grams) / 1.56 lbs. (708 grams)<br>• Approximately 1.5 - 3.5 hours / 2.5 - 9.0 hours (3) |
| Charger | greenworks 24 Volt Battery Charger, PN29862<br>• Input: 100-240 VAC; 50-60 Hz<br>• Output: 1.5A 19 VDC; 2.37A |
| **Notes:** | |

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

| |
|---|
| 1 - Must have evidence that testing of these respirators demonstrates performance at a level of protection of 1,000 or greater to receive an APF of 1,000. This level of performance can best be demonstrated by performing a WPF or SWPF study or equivalent testing. Absent such testing, all other PAPRs with helmets/hoods are to be treated as loose-fitting facepiece respirators, and receive an APF of 25.<br><br>2 - Temperature limits of ABS Plastic are -4º to 176º F (-20º to -80º C); Recommend storage no higher than 150º F (65º C)<br><br>3- Estimated system run time based on testing with a new battery and filter at 68º F (20º C). Actual system run time may be extended or shortened depending on system configuration and environment. Run time is also contingent on user selected flow rate. |

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# Appendix D - JPL Tests and Results

## Overview of Test Program

NIOSH published interim standards, which developed a new PAPR100 Class. This is created to be more in alignment with health care provider needs and environment. More information:

- https://www.cdc.gov/niosh/npptl/respstandards/papr.html
- https://www.federalregister.gov/documents/2020/04/14/2020-07804/approval-tests-and-standards-for-air-purifying-particulate-respirators

The JPL developed respirator is PAPR100-N, which is not for use against oil-based aerosols. The interim standards also established new testing guidelines, to approve PAPR100's for use. Previous NIOSH requirements for PAPRs encompassed construction-use cases. The new PAPR100-N classification enables a new Test Matrix, outlined in Table 11 below. JPL added Test #9 and Test #10, which are not required by NIOSH.

| Test Number | 42 CFR 84 Subsection | Test |
|---|---|---|
| 1 | 176(b) | Facepiece Fit with Tight Fitting Respiratory Inlet Coverings |
| 2 | 180 | Particulate Filter Efficiency Level Against Liquid Particulates |
| 3 | 180 | Particulate Filter Efficiency Level Against Solid Particulates |
| 4 | 171(j)(6) | Low Flow Warning Device Sound Level |
| 5 | 171(j) | Low Flow Warning Device Activation for Breath Assist Type |
| 6 | 171(j)(1) | Low Flow Warning Device Visibility |
| 7 | 171(j) | Low Flow Warning Device Activation |
| 8 | 181 | Communication Performance Test For Speech Conveyance And Intelligibility |
| 9 | -- | Pump Flow Rate and Filter characterization |
| 10 | -- | Life Cycle Testing |

*Table 11: NIOSH required tests for PAPR100-N*

NIOSH only approves manufacturers, not designs. As such, JPL pursued ensuring the design met the standards required by the tests. However, for the design to be able to be provided by employers to health care professionals, the manufacturer will have to solicit NIOSH approval by performing these tests. Testing procedures can be found here: https://www.cdc.gov/niosh/npptl/stps/aprespInterim.html

## Test 1: Facepiece Fit with Tight Fitting Respiratory Inlet Coverings

This PAPR design is subject to a fit check test, as required by 42 CFR 84 176(b). This test proves that the mask is sufficiently sealed to prevent entrainment of particles into breathing area. Wildhorn Outfitters completed fit testing in accordance with OSHA 29 CFR 1910.134: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.134AppA

More Wildhorn Outfitters information
https://www.wildhornoutfitters.com/pages/fullfacemaskcovid19-info

## Tests 2 and 3: Particulate Filter Efficiency Level

The filter design and material selection was based on JPL Respirator COVID19 efforts. More detailed results about that selection and test process can be found at: https://medeng.jpl.nasa.gov/covid-19/respirators/. The 42 CFR 84 testing requirements are identical for the two types of respirators.

## Test 4: Low Flow Warning Device Sound Level

The purpose of this test is to ensure the sound level of low flow warning is sufficient for the user to detect the alarm. A noise dosimeter, with built-in A-weighting network was utilized for this test.

The background noise level of the room was measured to be 48.5 dBA, which is less than the 60 dB requirement.

Operator tested that when flow rate was reduced below 115 L/min, the low flow alarm exceeded 80 dB at the operator’s ear. The noise level measured was 80.9 dB, passing test requirement.

*Figure 78: Test demonstrating that noise level at operator’s ear is greater than 80 dB.*

# Test 5: Low Flow Warning Device Activation for Breath Assist Type

The purpose of this test is to demonstrate the low flow warning will:

1. Activate when flow falls below 115 L/min
2. Require no intervention by the wearer
3. Warning cannot be de-energized while the blower is energized
4. Distinguishable from other alarms

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

To verify the respirator design meets the above requirements, a bench test was performed and wiring was appropriately designed.

On a bench test, the flow meter was connected to a data acquisition system. When the flow rate dropped below 115 L/min, the alarm sounded and the visual indicator (red LED) activated.

The wiring circuit is designed such that the warning alarm is wired directly to the power source of the blower. Therefore, it is impossible to de-energize the warning device while the blower is energized.

There are no additional alarms, therefore the low flow warning is distinguishable.

As such, the respirator meets all of Test 5 requirements.

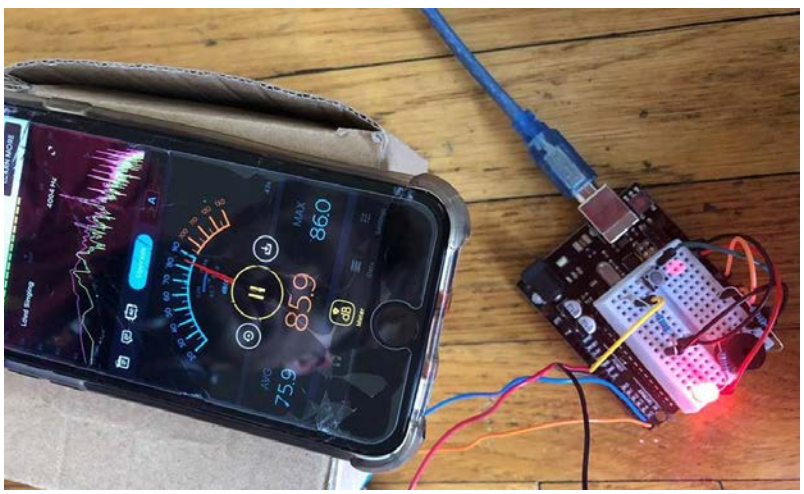


*Figure 79: Bench test verifying alarm activated below 115 L/min, and initiated an auditory alarm >80 dB.*

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

# Test 6: Low Flow Warning Device Visibility

The purpose of this test is to confirm the visual indicator is visible.
Test subject confirmed the visual indicator was visible, when the low flow alarm went off.

*Figure 80: Visual indicator for low flow alarm activated.*

# Test 7: Low Flow Warning Device Activation

All requirements were met by Tests 4 and 5.

# Test 8: Communication performance Test for Speech Conveyance and Intelligibility

To confirm adequate communication and intelligibility, two engineers conducted tests:

- Standard communication in a laboratory with background equipment noise
- Laboratory setting while not facing test proctor.
- Outdoors
- Walking

Based on these tests, this PAPR design is expected to pass a Modified Rhyme Test, as required by 42 CFR 84.181.

*Figure 81: Outdoor communications test*

# Test 9: Pump Flow Rate and Filter Characterization

Test set-up:

- Blower energized with power supply
- Flow meter, data recorded on laptop
- Filter assembly, with seal and filter installed
- Two analog pressure gages
- Orifice sized to mimic system back pressure

Testing configuration was set-up to be representative of actual assembly. Flow was varied, utilizing blower potentiometer. At incremental steps, pressure drop across the filter and recorded against flow meter measured flow rate. Flow losses across filter were decidedly negligible.

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

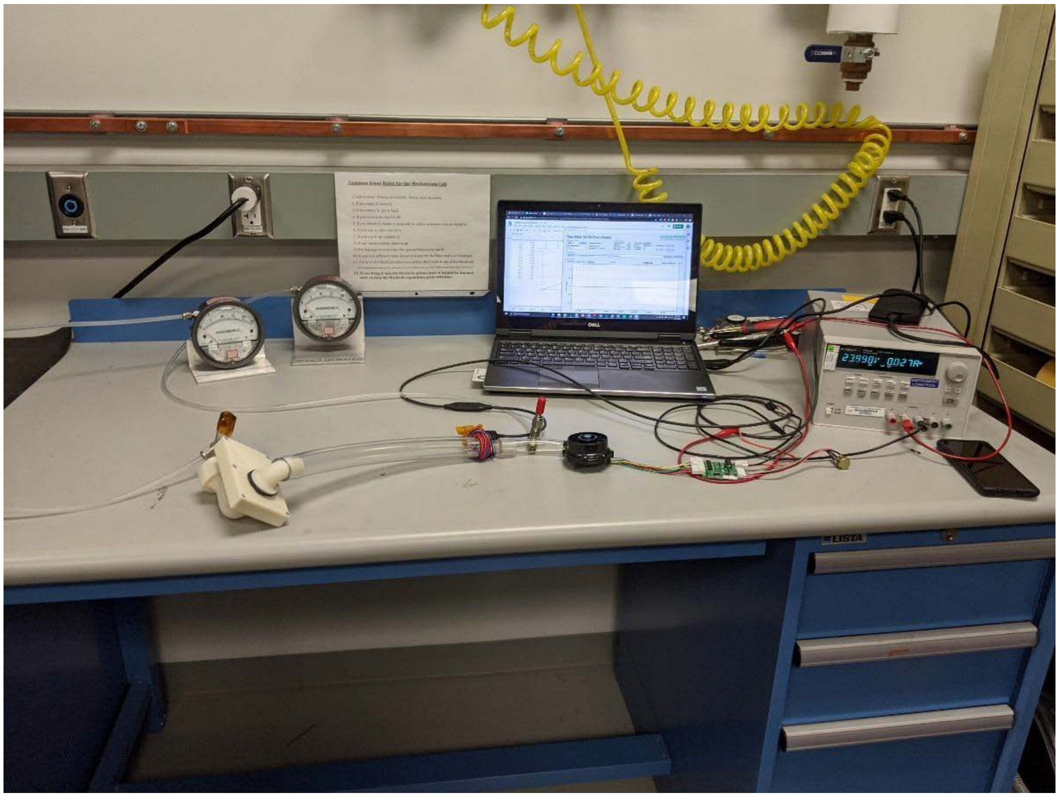

*Figure 82: Test configuration for flow rate and pressure drop determination.*

*Figure 83: Internals of filter, as-assembled for test*

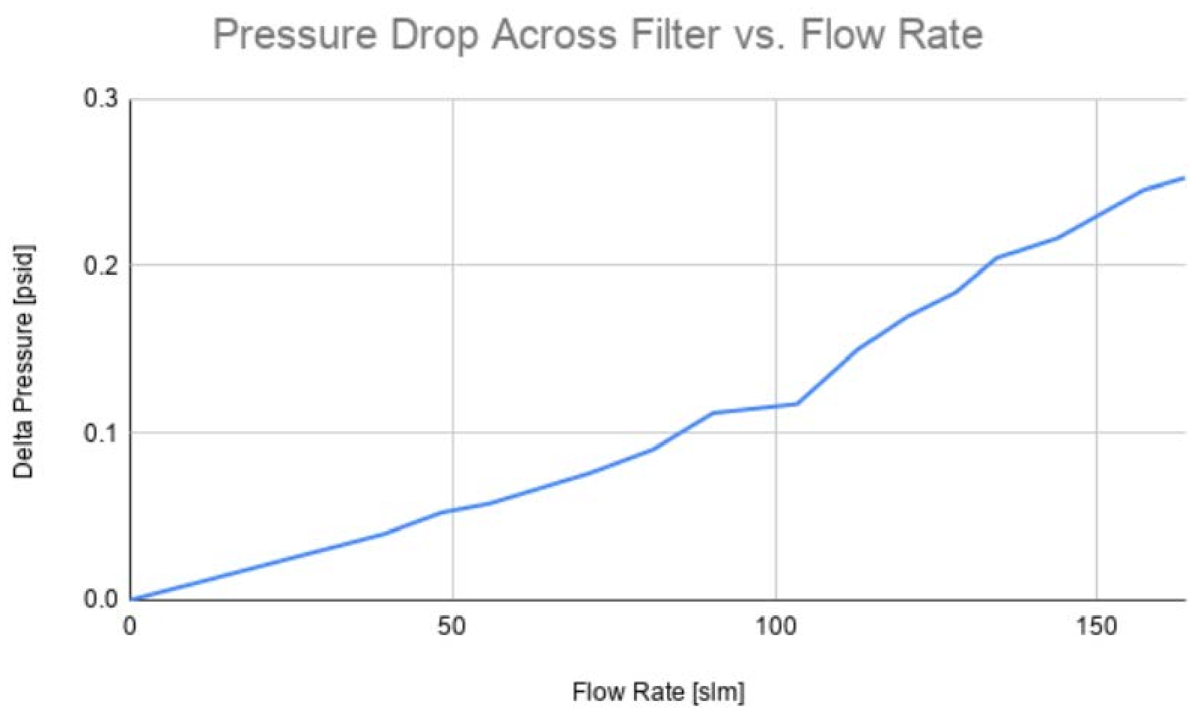


*Figure 84: Flow Drop across filter at varying flow rates.*

# Test 10: Life Cycle Testing

Life Cycle testing was performed on fully assembled PAPR units, at extreme flow rates.

Testing set-up:

- All testing was performed without any breathing back pressure. This was the conservative test assessment, since with these blower designs, increased back pressure reduces current draw. Thus as a person breathes, they are creating back pressure on the blower, subsequently reducing the power draw from the battery.
- Flow Rate was tested at the two extreme flow rates.
    - Blower flow rate was maintained as slightly above alarm level (115 L/min).
    - Maximum flow rate

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

- If flow rate dipped below the alarm threshold of 115 L/min, the blower potentiometer was adjusted to increase flow rate. This was done until maximum flow rate was achieved.
- Test was concluded, and duration recorded, when alarm sounded continuously for 30 s.

Test Results:

| **Battery Pack** | **Duration of Battery Life** |
|---|---|
| 2 Ah | 1.5 - 3.5 hours |
| 4 Ah | 2.5 - 9.5 hours |

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration