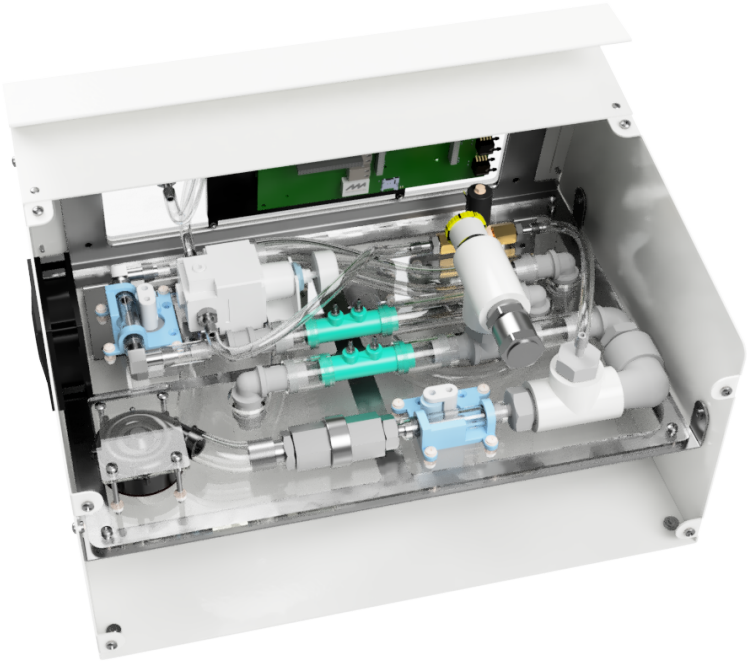
03-02 – Assembly Instructions



This document contains instructions on how to assemble the component parts as well as the entirety of the ventilator prototype. Note that these are the instructions to assemble the v0.2 prototype, which is still subject to significant revision. These assembly instructions are adapted from the prototype build and are not necessarily instructive for the full ventilator. Please consult with info@respira.works before purchasing to ensure the status of the design.

These instructions reference part numbers identified in 04-01 Complete BOM.xlsx

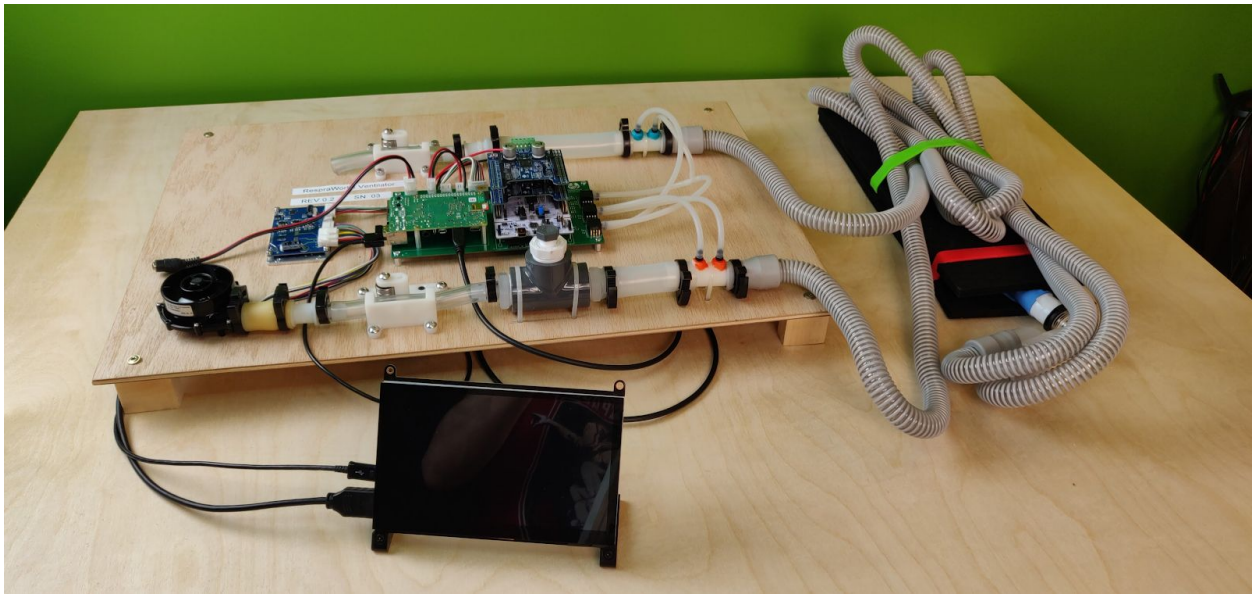
Release Information

Approval	Revision	Revision Date
Ethan Chaleff	A	6/21/20

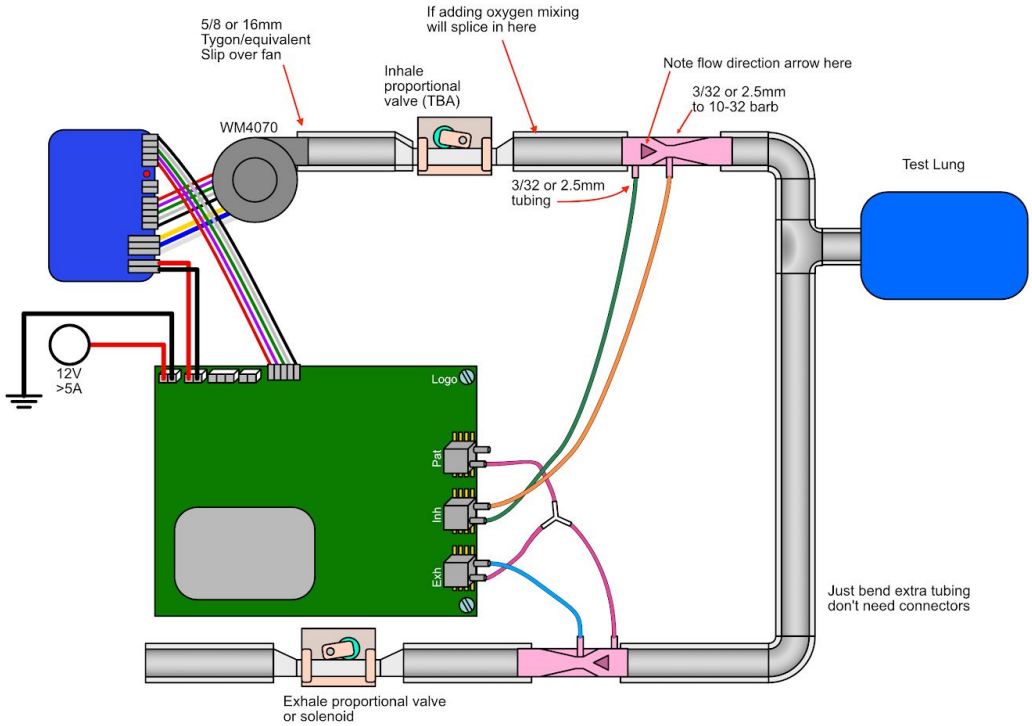
Overview

This is a ventilator prototype for testing and development. The build consists of a functional ventilator pneumatic assembly with controller and user interface. This build is adequate for integration and systems testing. It lacks heating, humidification, battery backup and air filtering. It is not enclosed like the final product and is meant to be operated in an open layout.

The prototype assembly is shown below, note that the oxygen inlet line is not included in this prototype.



A graphical representation of the components, highlighting the interfaces for the prototype are shown below.



A. Assemble sensors, drivers, and pneumatic components

First, you will need to assemble the sub-components of the ventilator.

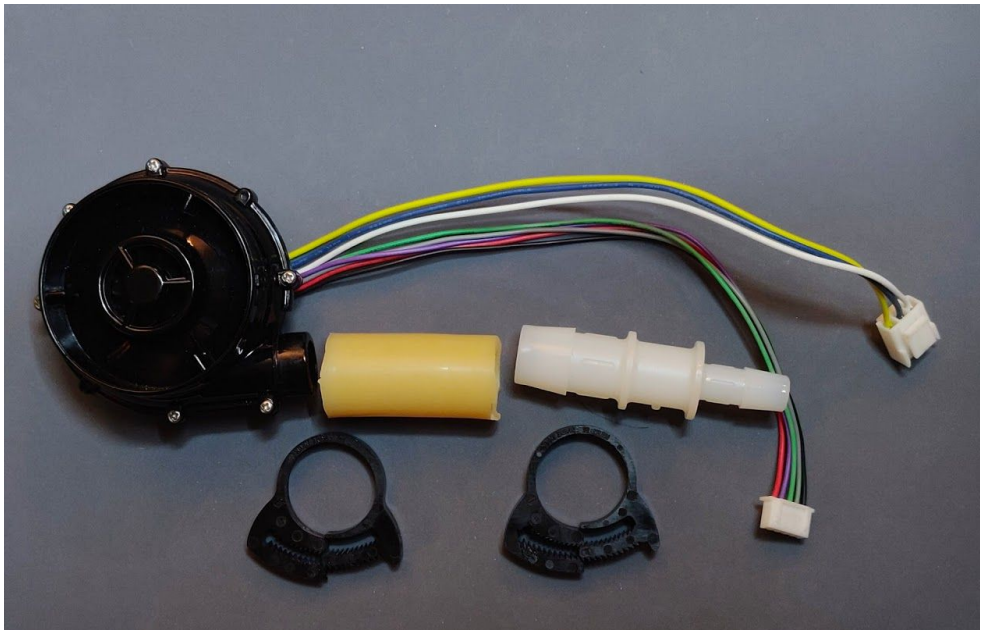
- **Blower:** The main driver of pressure in the pneumatic circuit.
- **2 Venturi flow sensors:** To provide the controller feedback.
- **Proportional pinch valve:** A proportional pinch valve can control the airflow constriction with much better precision. Multiple such pinch valves are used in the prototype, the part is buildable from 3d-printed plastic components and easily obtainable generic parts. The ventilator requires two pinch valves.
- **Oxygen supply limb (in development)**

Use the pictures and diagram above to help with assembly.

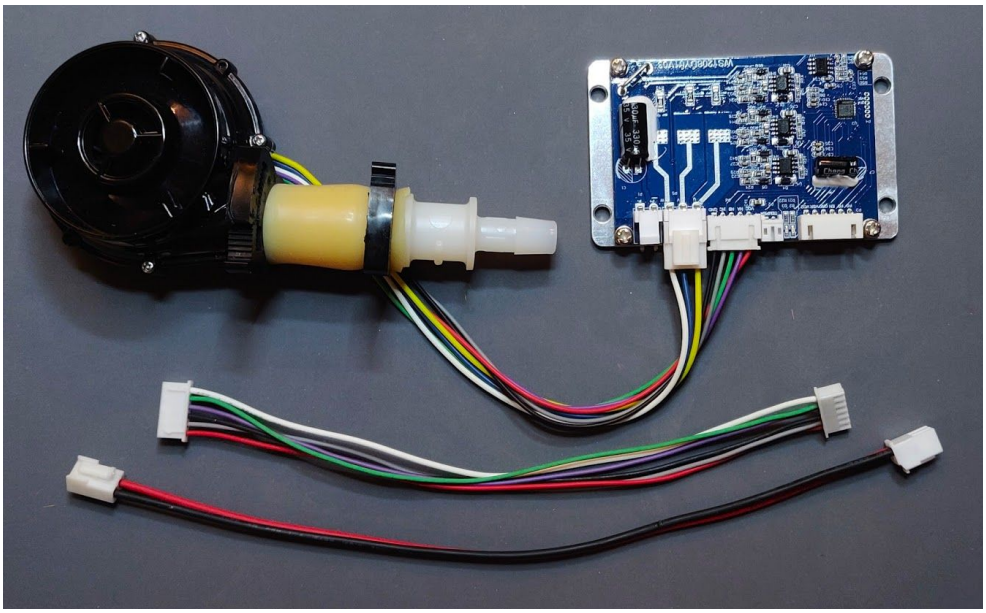
Note: Mind which tubes go into the bottom and top ports of the sensors on the PCB.

Blower

The blower/fan is what provides air pressure to the ventilator's pneumatic circuit. The pneumatic aspect of the blower assembly includes the blower and a short segment of tubing compatible with blower outlet diameter. The electrical aspect of the blower assembly encompasses the driver board and wires of sufficient length to interface with the PCB.

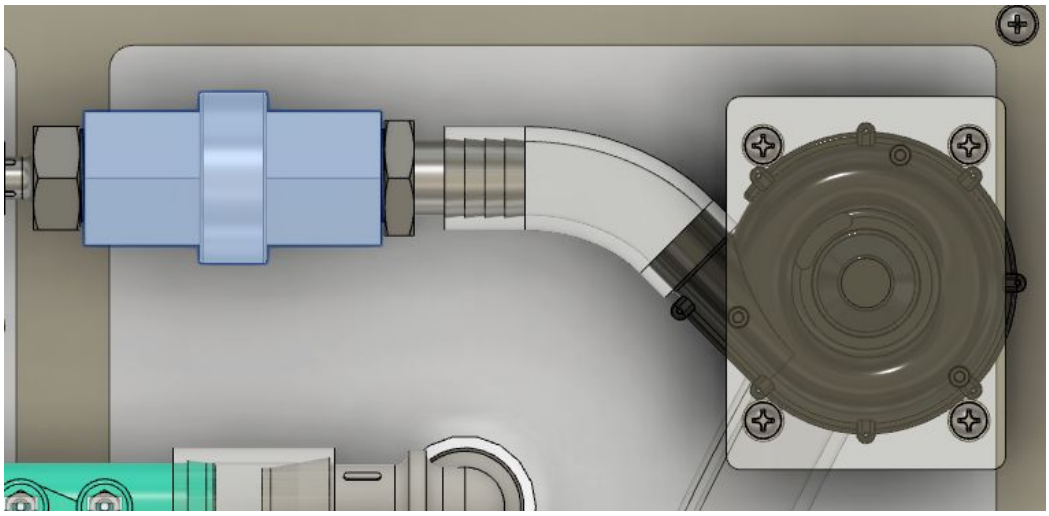


1. Use short segment of tubing. Use Herbie clip to secure tubing to blower. Alternatively, you can use a zip-tie.



2. You will have to crimp connectors to the second end of the wiring that connects the driver board to the PCB. It depends on your build layout, but in the case that you need longer wires, you will have to crimp both ends. In this case you will need a higher number of XH and VH connector components.

Note that the check valve is not shown in the above setup but should be included with any build where oxygen is used. The check valve is visible in blue in the image below.



Venturi Flow Sensors

Currently the design is 3D printed using an SLA printer. Once the geometry is finalized we will experiment with a much simpler orificing venturi, or design for manufacture (DFM) the final venturi. The venturi outer diameter is defined by the tubing standard.

The pressure sensor we are using, the MPXV5004DP (see below) has 2.5 mm or 3/32" barbs. Note that this is not sufficiently close in size to use more common 3mm or 1/8" tubing. This model has printed threads to accept an adapter from #10-32 pipe to 3/32" adapter. Other adapters could be incorporated eventually by changing the interface design.

You can use a zip tie or hose clamp to improve the seal by tightening it behind the barb.

There is an arrow printed onto the body between the two ports to indicate the direction of flow. The venturi is asymmetrical, with a tighter constriction on entrance than exit

The beta version of the ventilator uses 3/4"ID or 19mm ID tubing throughout.

Files

- .stl format[1]
- .iges format[2]
- .f3d format[3]

3D Printing

These should not be printed with FDM. Instead, a leaktight method like SLA or MJF should be used. Also, this model contains printed threads and is designed to interface with the referenced McMaster barbed fitting.

Note that the flow measurement is very sensitive to the exact geometry, particularly the thread geometry. 3D printing can have variable shrinkage that results in uncertainty in the throat size, and thus the flow rates. Check the diameter of the printed venturi; a good way to do this is to put a drill into the venturi that just barely fits, and then measure the diameter of that drill bit, or to ream the final part to size with a 5.5 mm

1 https://github.com/RespiraWorks/SystemDesign/blob/master/research-development/project-venturi/assets/venturi-3-4.stl

2 https://github.com/RespiraWorks/SystemDesign/blob/master/research-development/project-venturi/assets/venturi-3-4.iges

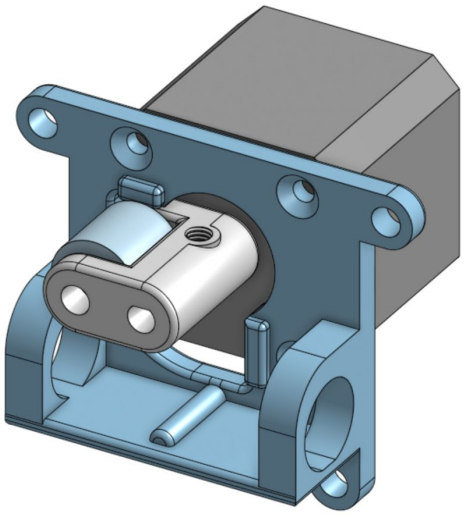
3 https://github.com/RespiraWorks/SystemDesign/blob/master/research-development/project-venturi/assets/venturi-3-4.f3d

Assembly

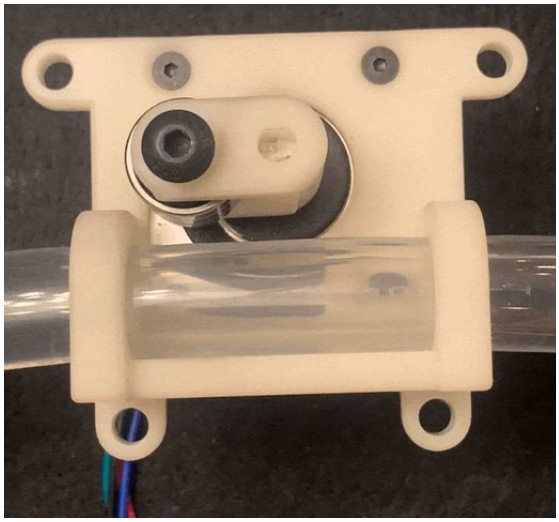
Screw the nipples into the 3d-printed venturi. There are threads in the print but they don't always come out right if resin gets trapped in the grooves while it prints. In such a case you might need a tap (listed in tooling BOM) to clean the threads. You do not need a bottoming tap, since there is enough depth in the holes and the threads are short.

In the latest tested version, no hand-tapping was required to insert nipples. With good enough 3d printing, this step should not be necessary.

Stepper Proportional Pinch Valve



CAD file



In Action

These files should not be printed with FDM. There are significant forces on the rotor, and an ABS like resin with SLA or FJM printing should be used. Alternatively, this part should be machined from ABS or aluminum. See 05-1 for discussion of volume production methods.

Files

- Base - .step format[4]
- Rotor - .step format[5]

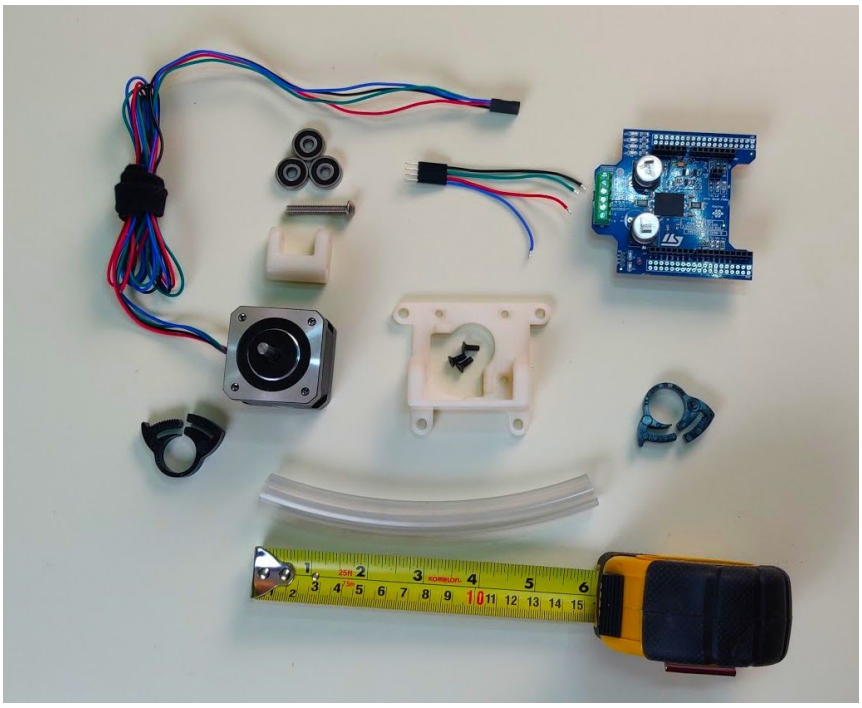
Original designs found here[6].

4 https://github.com/RespiraWorks/SystemDesign/blob/martukas-patch-1/research-development/project-pinch-valve/assets/exhaust-pinch-valve-1.6-base.step

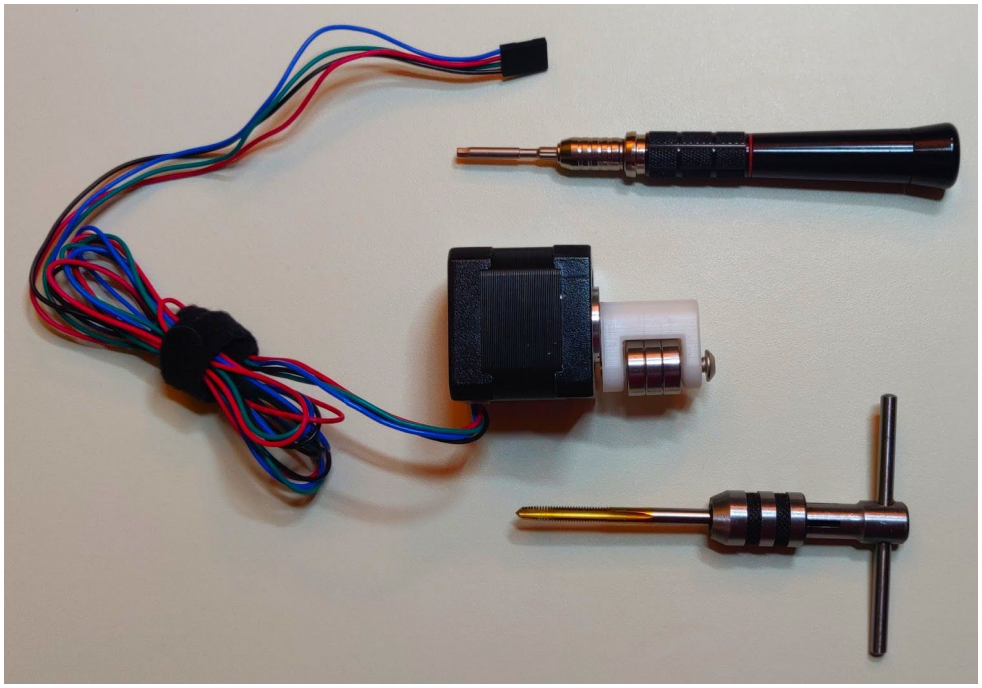
5 https://github.com/RespiraWorks/SystemDesign/blob/martukas-patch-1/research-development/project-pinch-valve/assets/exhaust-pinch-valve-1.6-rotor.step

6 https://cad.onshape.com/documents/3fe0c1f79c482144c267173d/w/2ad1c08071a25185f9c78c68/e/03a49465e4e026f9f102d0af

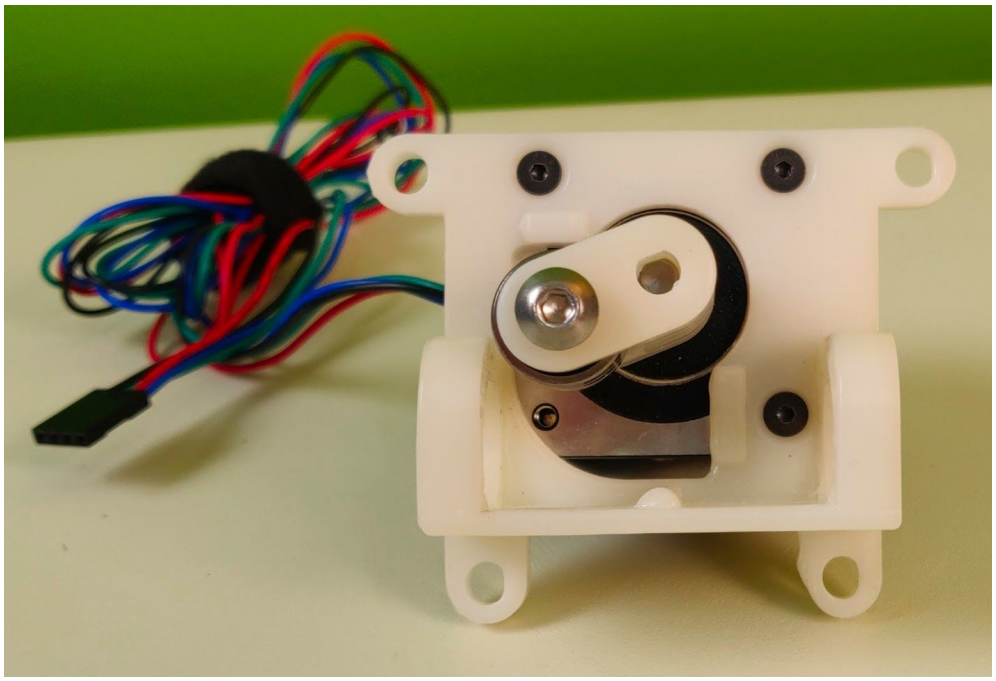
Assembly



You'll need a vice to press on the rotors to the stepper motor shafts. You may also need a tap to chase the threads in the rotor for the bolt holding the bearings. On some machines they print too tight and you may crack the rotor trying to just muscle in the bolt without chasing the threads first. Only chase a portion of the threads for the bolt that holds on the bearings, leaving a bit to act as a lock nut.



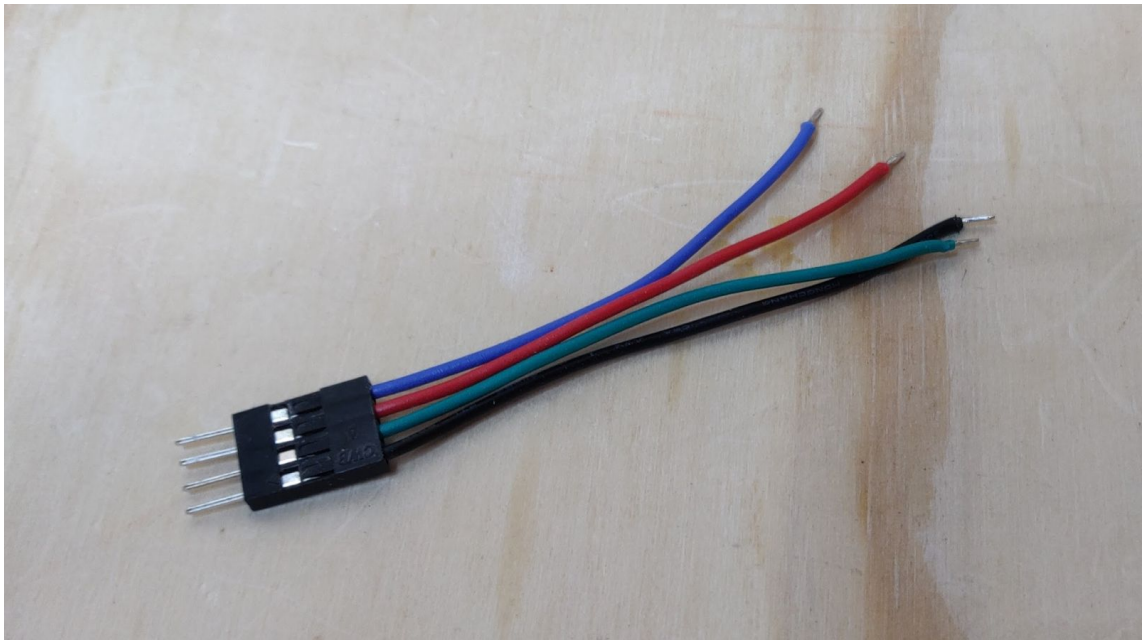
Rotor assembly - 3mm hex and 2.5mm hex driver are required for assembling rotor.



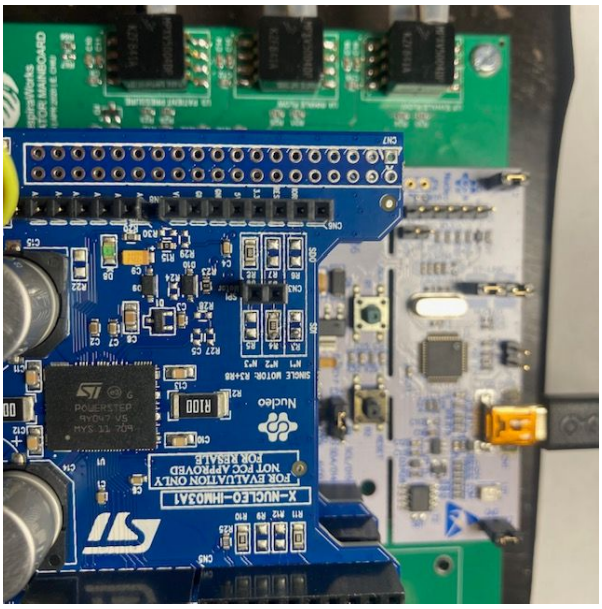
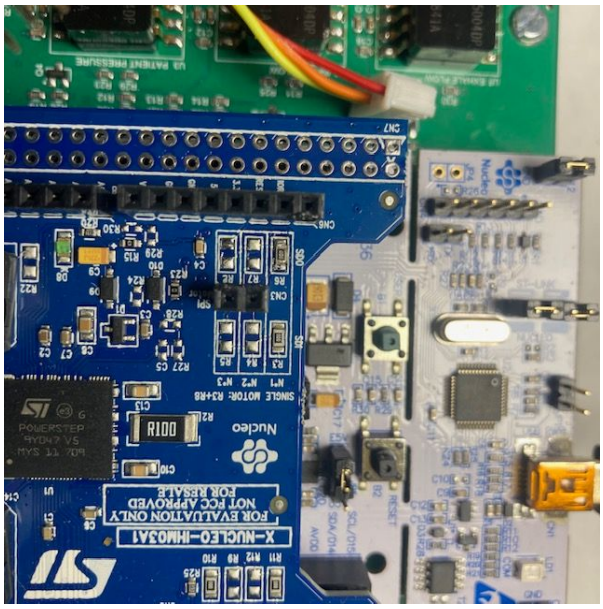
Base Assembly - 2mm hex driver is required for attaching base.

Each pinch valve must also include some additional wiring and a driver board for controlling the stepper motor.

A pigtail with male dupont connectors must be manufactured for interfacing to the driver board:

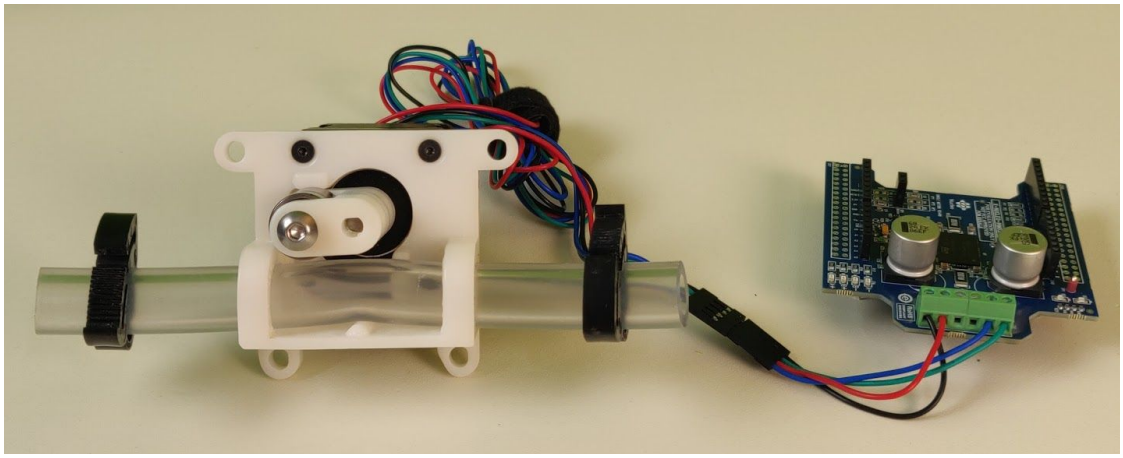


Since one ventilator unit contains two pinch valves, each must come with its own driver board configured as follows:

Top board	*Bottom board*
	

Note the positions of the resistors R3-R8. They must be resoldered appropriately.

Including the ⅜”ID ⅝”OD tygon tube and clamps, the full pinch valve sub assembly appears as follows:



Assembled

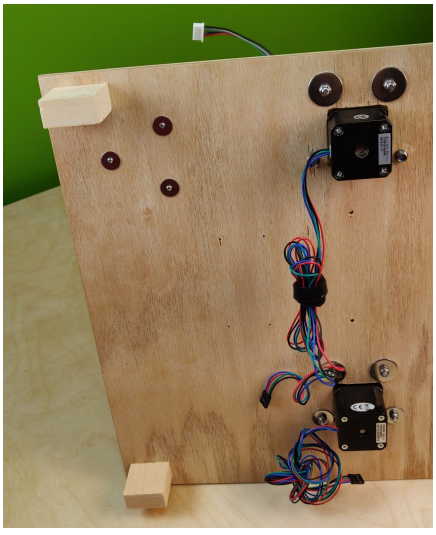
B. Create base for tabletop ventilator prototype

A base for the table top ventilator can be created out of any sturdy material, such as plywood, preferably with some 4cm high supports:

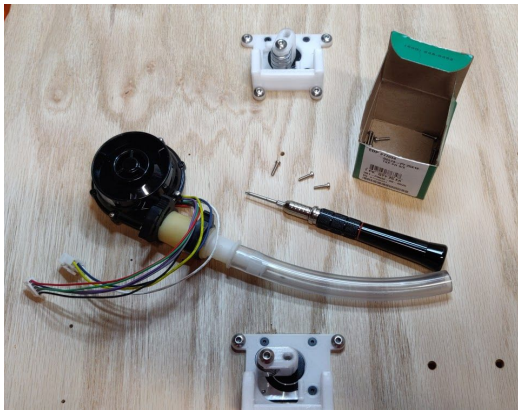
In the picture on the right we have marked down positions for the components to be attached.

C. Attach Sub-Assemblies

1. Bolt down the pinch valves to the base using some M5 bolts, washers and lock nuts.

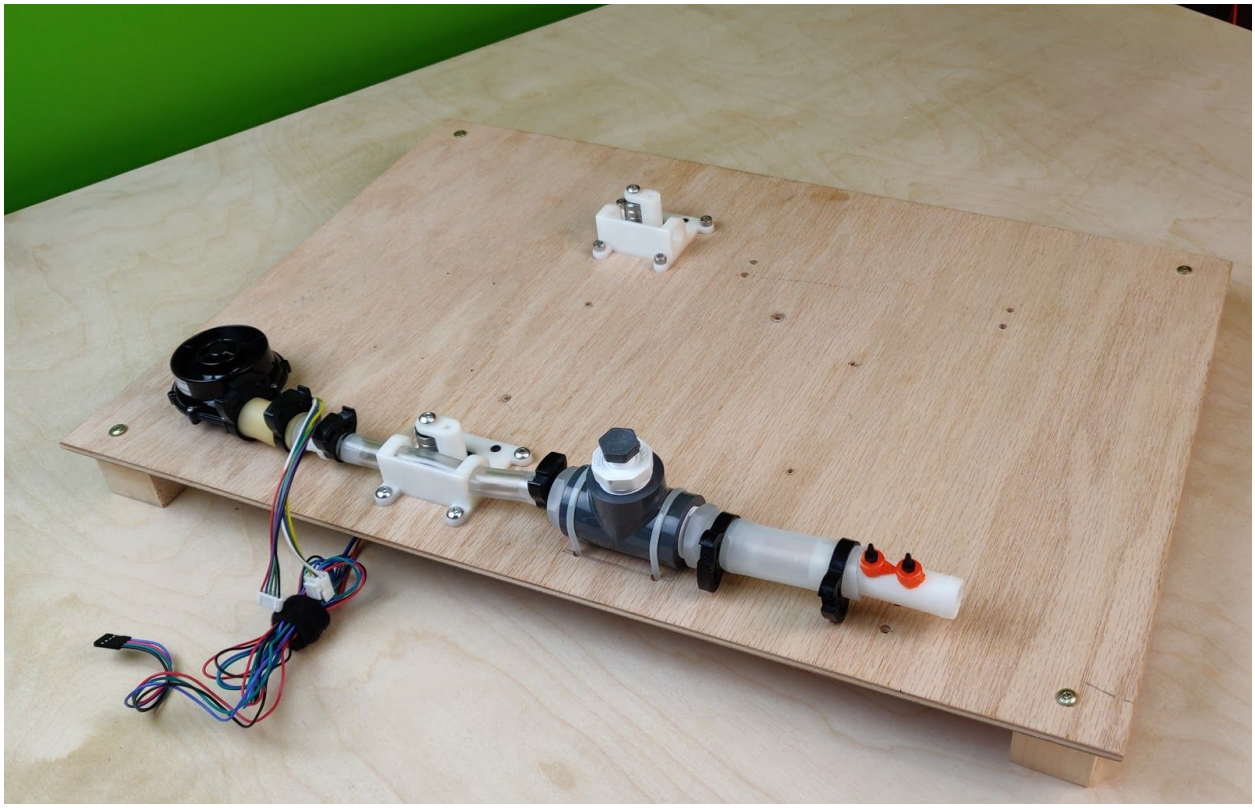


2. Take the tube that belongs with pinch valve and attach it to the blower sub-assembly. lide the tube through pinch valve and bolt down the blower from the back, using some M2.5 thread-forming screws:

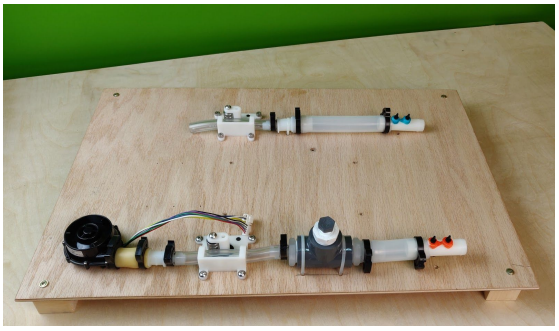


3. Assemble a tee for the oxygen branch (in development), with a transition from ⅜”ID tubing to ¾”ID tubing, about 8 inches of ¾”tubing and the inflow venturi. Here we have highlighted the flow direction arrow on the venturi:

4. Connect the oxygen tee and venturi to the first pinch valve to complete the inhale limb of the pneumatic assembly:



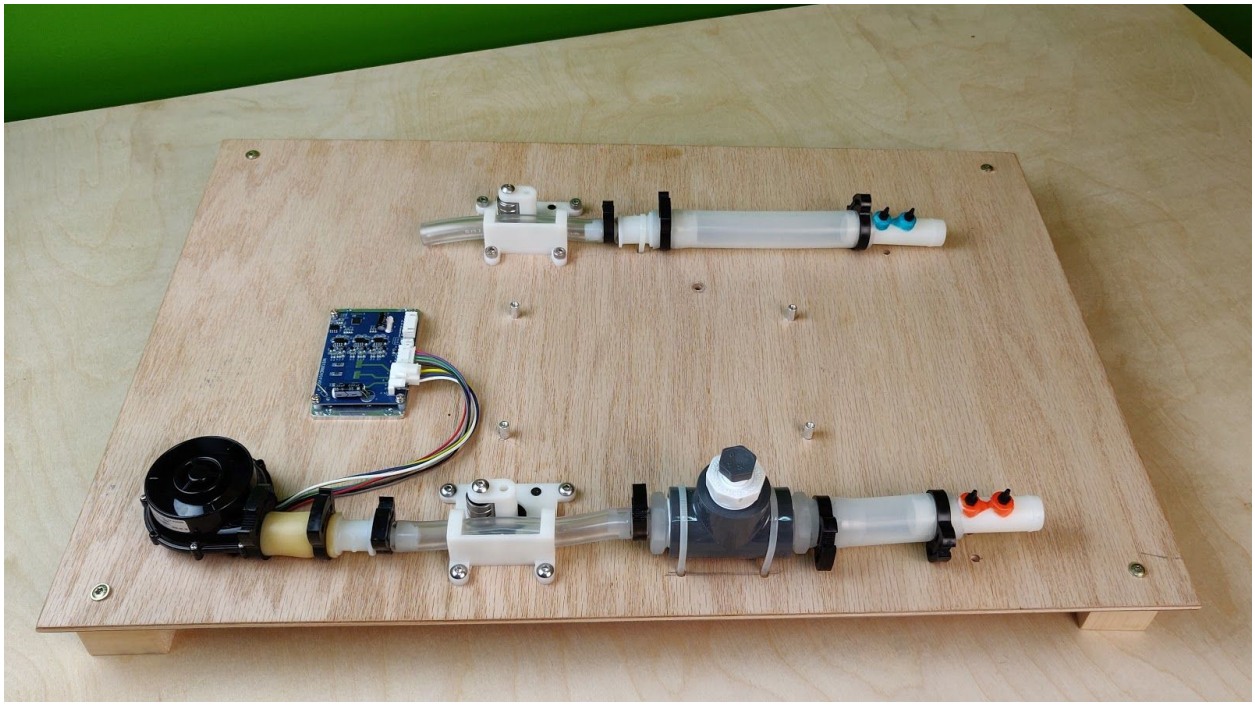
5. Assemble the exhale limb of the pneumatic assembly, which includes the outflow venturi, 15cm of ¾”ID tubing, a tubing adapter and the ⅜”ID tubing for the second pinch valve. Then, slide it into the pinch valve and zip tie the adapter to secure it to the base board.



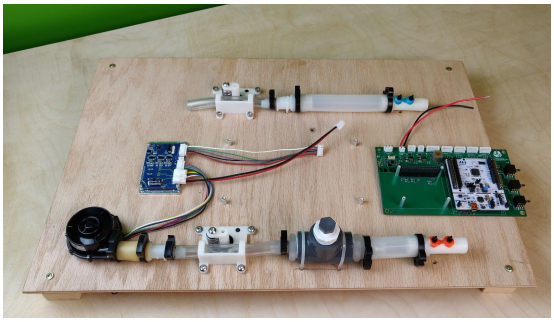
D. Assemble electrical components

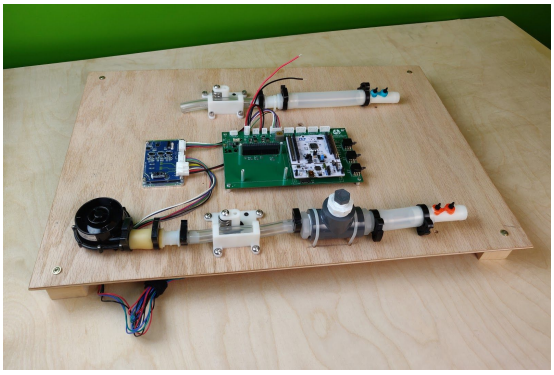
These computing and digital user interface components enable full deploy and execution of all developed software.

6. Secure the blower driver board to the base and attach spacer standoffs for supporting the main circuit board:



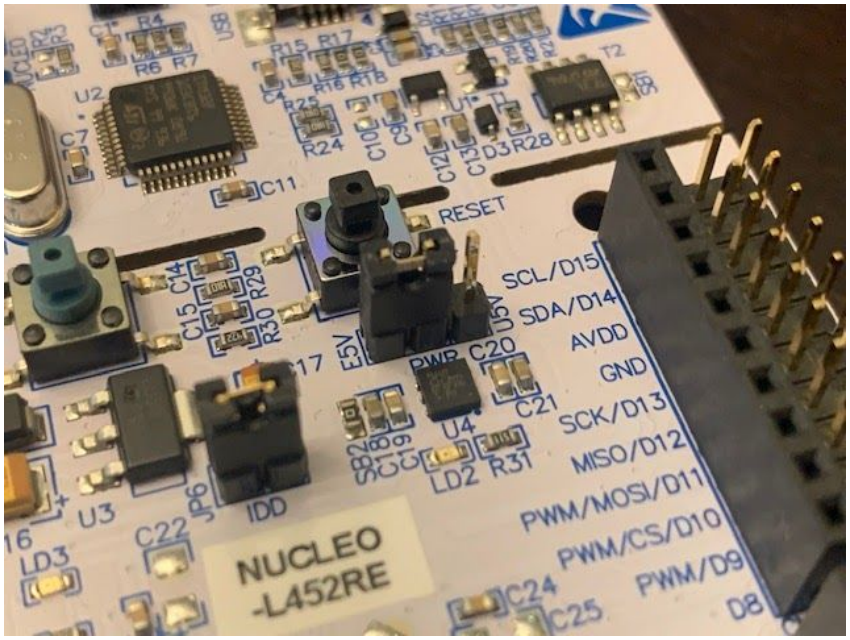
7. Install the PCB, running the blower's power and control cables in the space between the base board and the PCB:



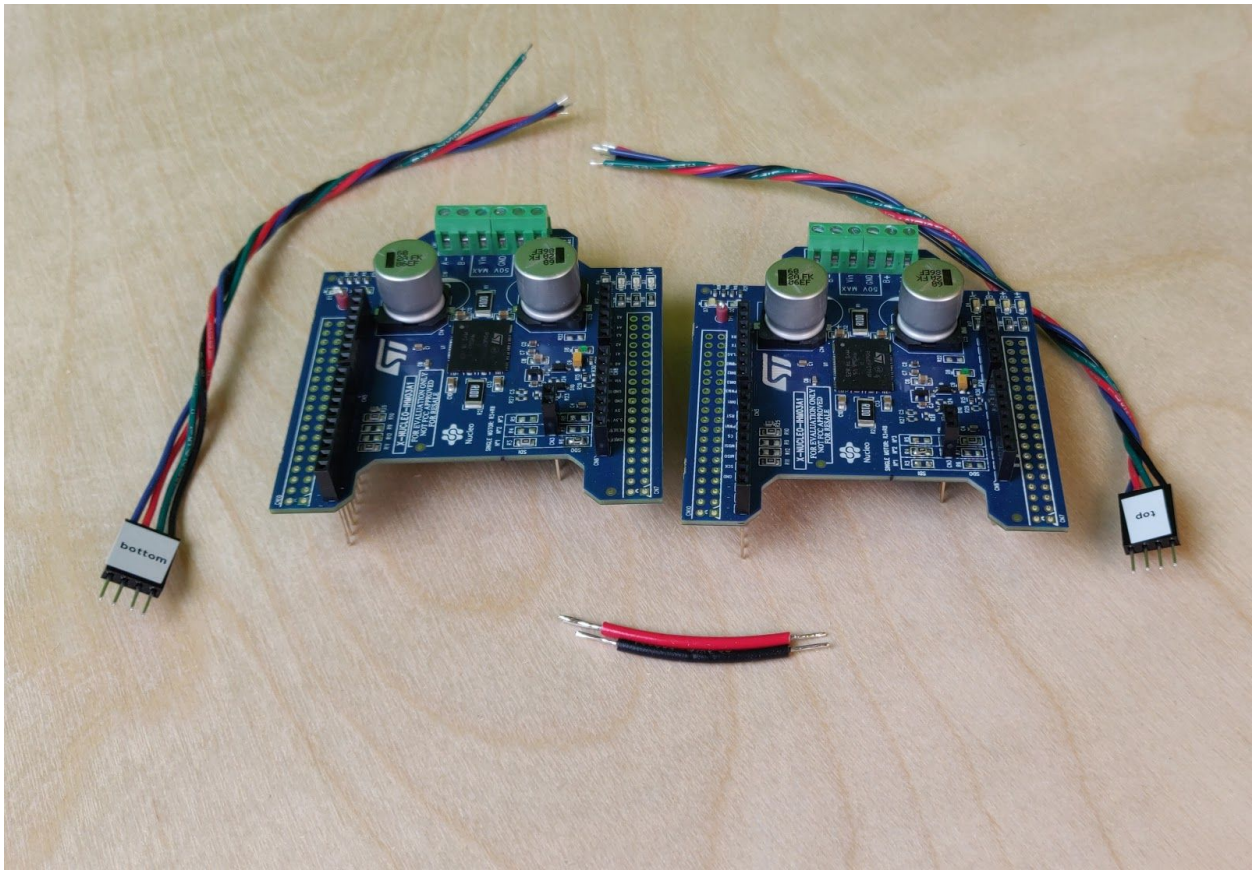


8. Move the JP5 jumper in the upper-middle-center of the Nucleo board to the E5V position. This tells the board to expect external power from the PCB. This will avoid programming problems. If you wish to remove the Nucleo board and work with it on its own without the

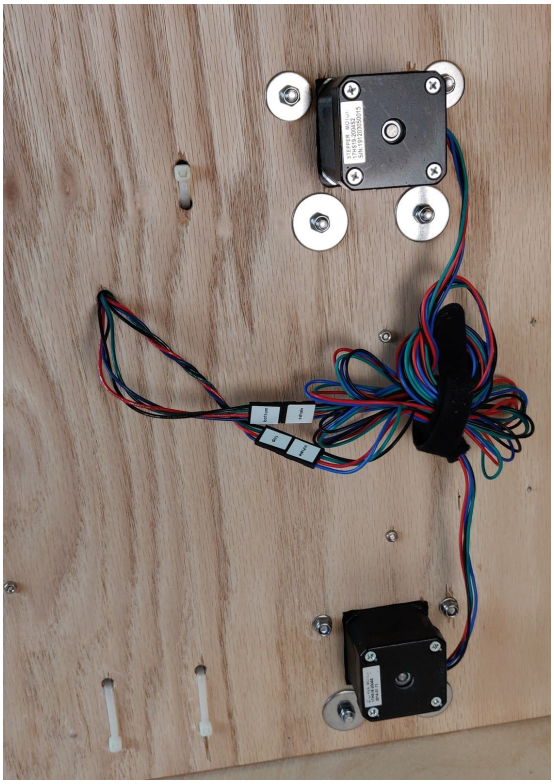
PCB, move the jumper back to the U5V position to power it from USB.

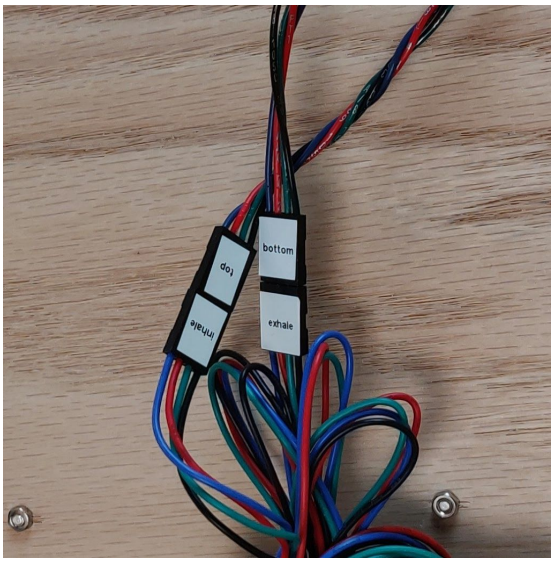


9. Prepare the stepper boards, and label the pigtails accordingly. Also prepare a couple of 16AWG wires (~4cm each) for powering both boards.

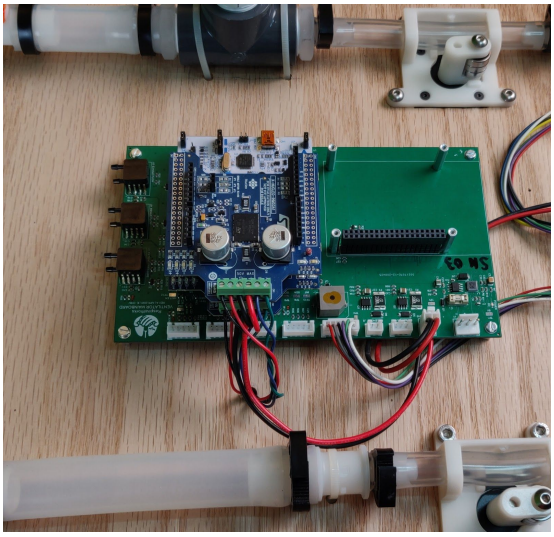


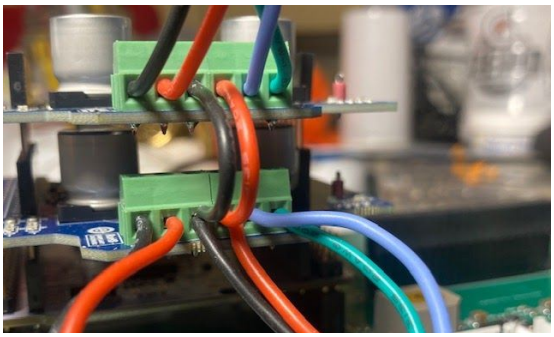
10. Run the pigtails from the back of the board, connecting them to the pinch valves as follows:





11. Stack the stepper boards onto the Nucleo and wire up as follows:



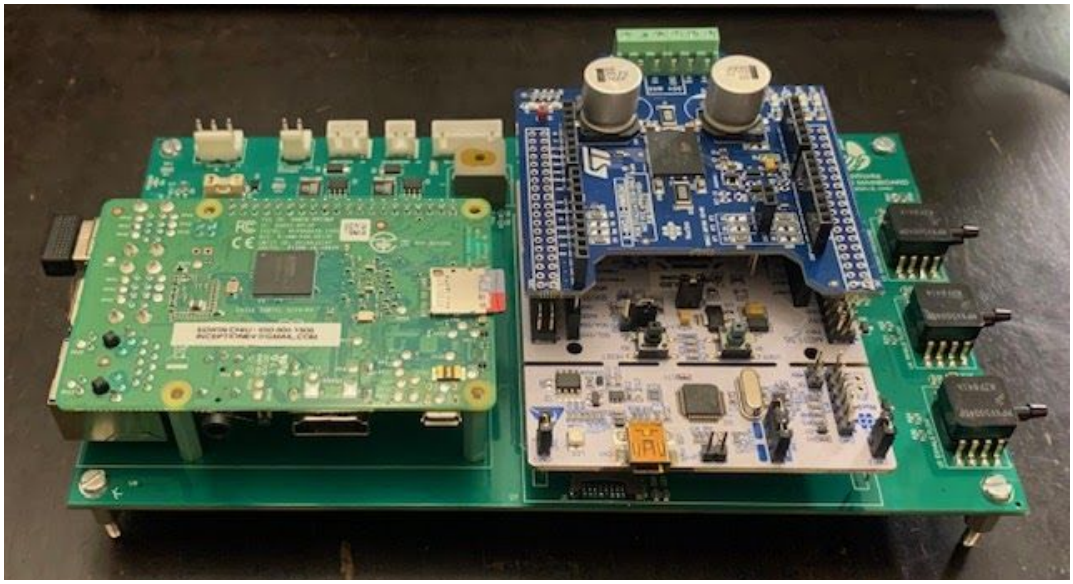


Additional schematic and model files can be found at the RespiraWorks: [open source documentation page](https://github.com/respiraworks/pcbreathe)[7] for this part.

[7] https://github.com/respiraworks/pcbreathe

Raspberry Pi

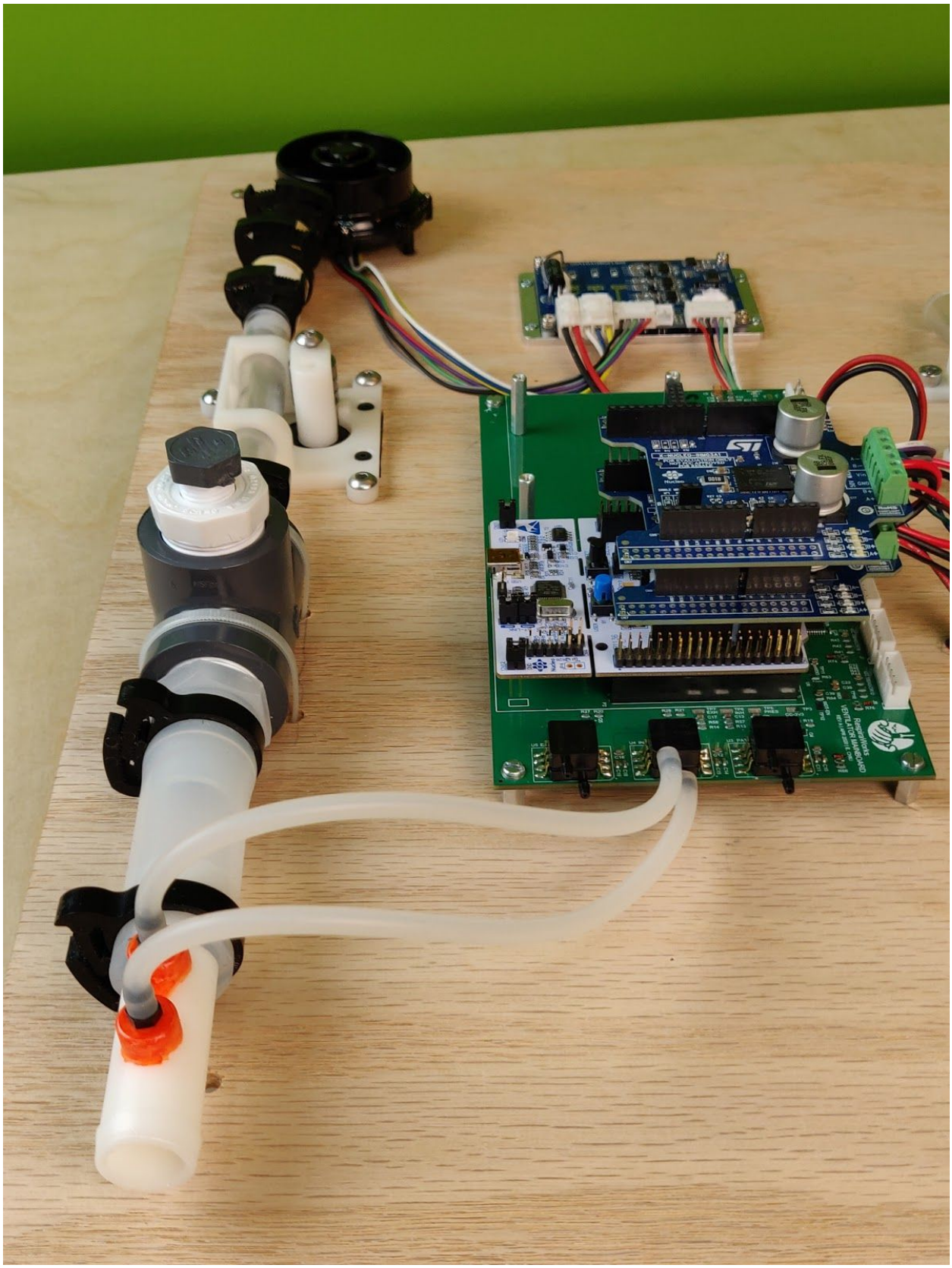
Plug Raspberry Pi 4 into the Raspberry Pi socket. Note that if you have the standoffs fitted, do not over-tighten them as this can damage the Raspberry Pi.



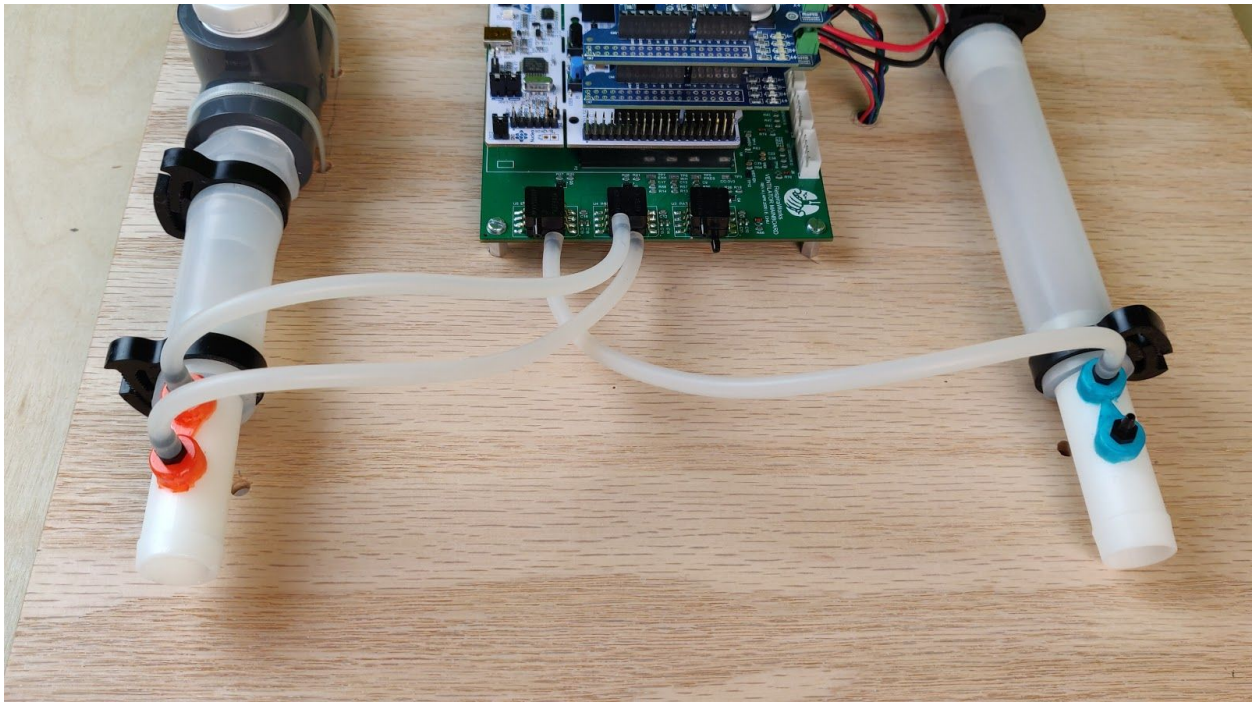
E. Connect sensor tubing

Connect tubing to the exhale venturi and inhale venturi, check the arrow on the venturis for direction to ensure the ports are correctly oriented. Connect the tubing from the inhale venturi to the board mounted pressure sensor using 2.5mm tubing. Note that of the two ports on the differential pressure sensors on the circuit board - the upper port must connect to the upstream orifice of the venturi, while the lower port must connect to the downstream orifice.

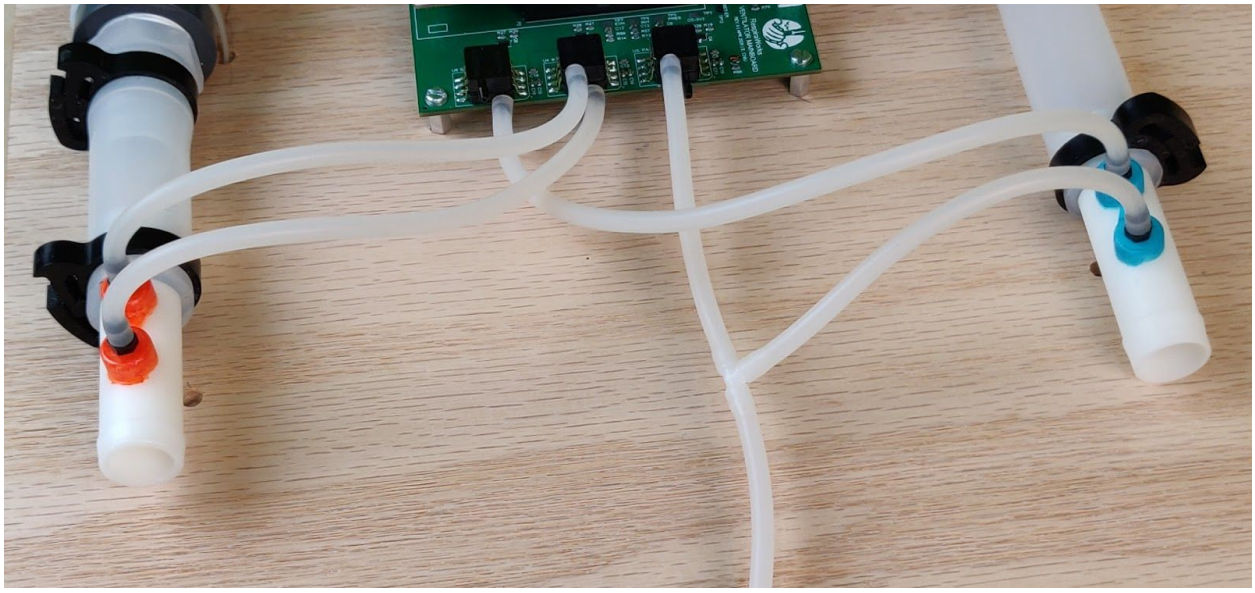
1. Fist, connect tubing to the inhale venturi. The tubes should be about 20 and 18 cm long.



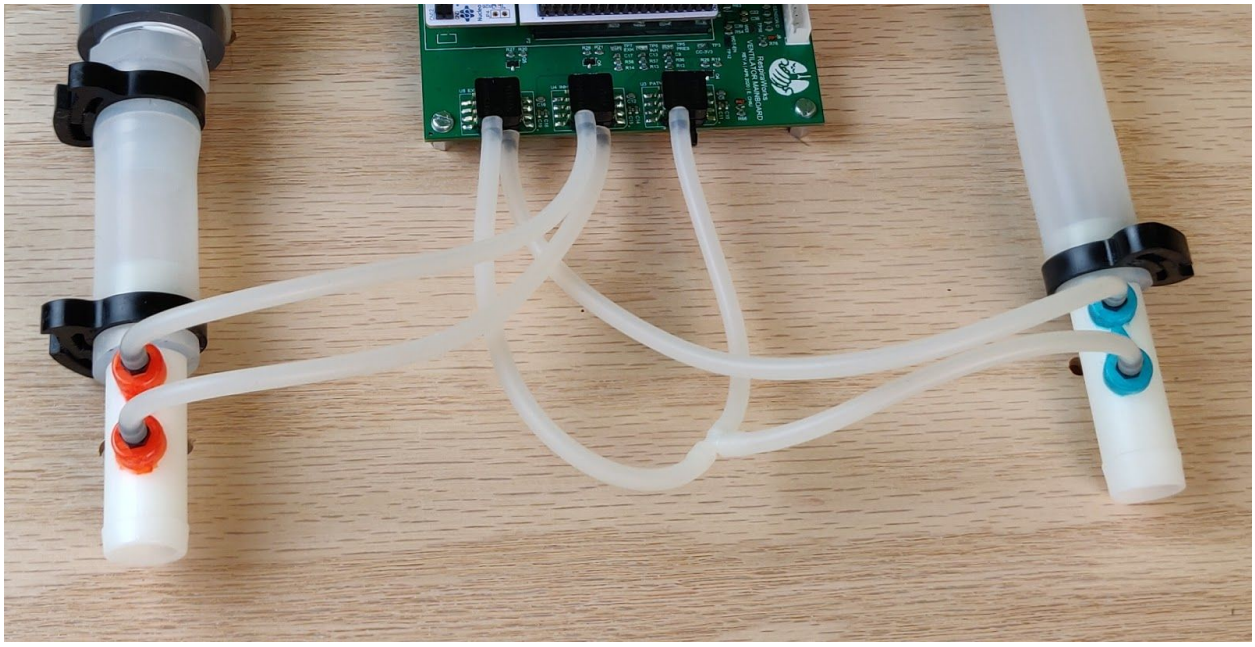
2. Now, connect a tube about 25 cm long from the downstream of the exhale venturi to the lower port of the exhale sensor.



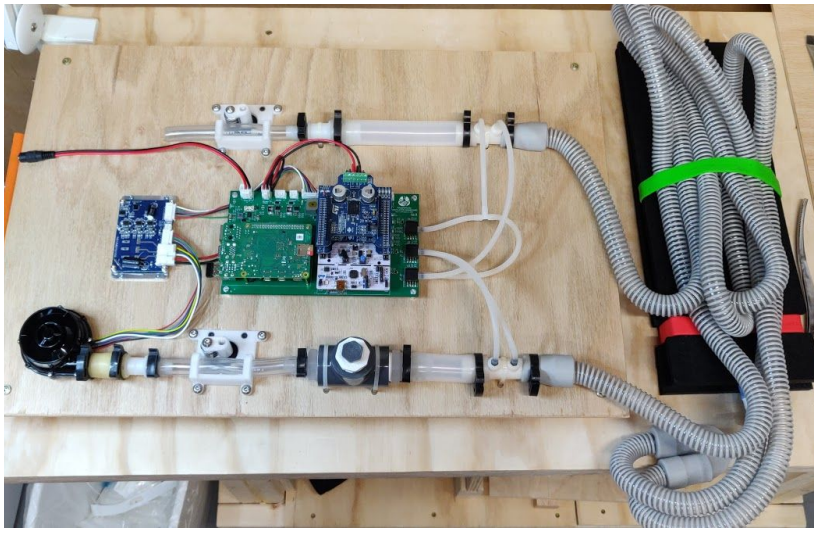
3. Run a tube (13cm) from the upstream orifice of the exhale venturi to a tee connector, and another tube (10cm) from tee connector to the upper port of the patient pressure sensor.



4. The last tube (15cm) runs from the tee connector to the upper port of the exhale sensor.



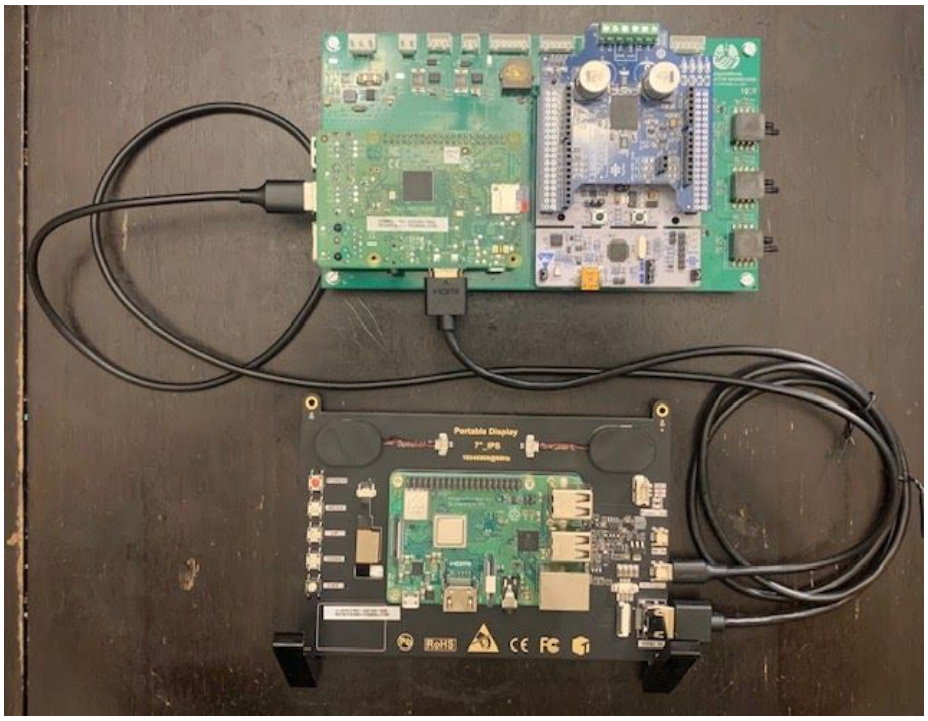
5. Lastly, you may connect the test lung to the venturis, clamp the patient tubing and secure the venturis to the board with some zipties:



F. Connect touchscreen

Connect an HDMI cable (included with Touchscreen package) between the Pi and the Touchscreen. Similarly, connect a USB micro cable (included with Touchscreen package)

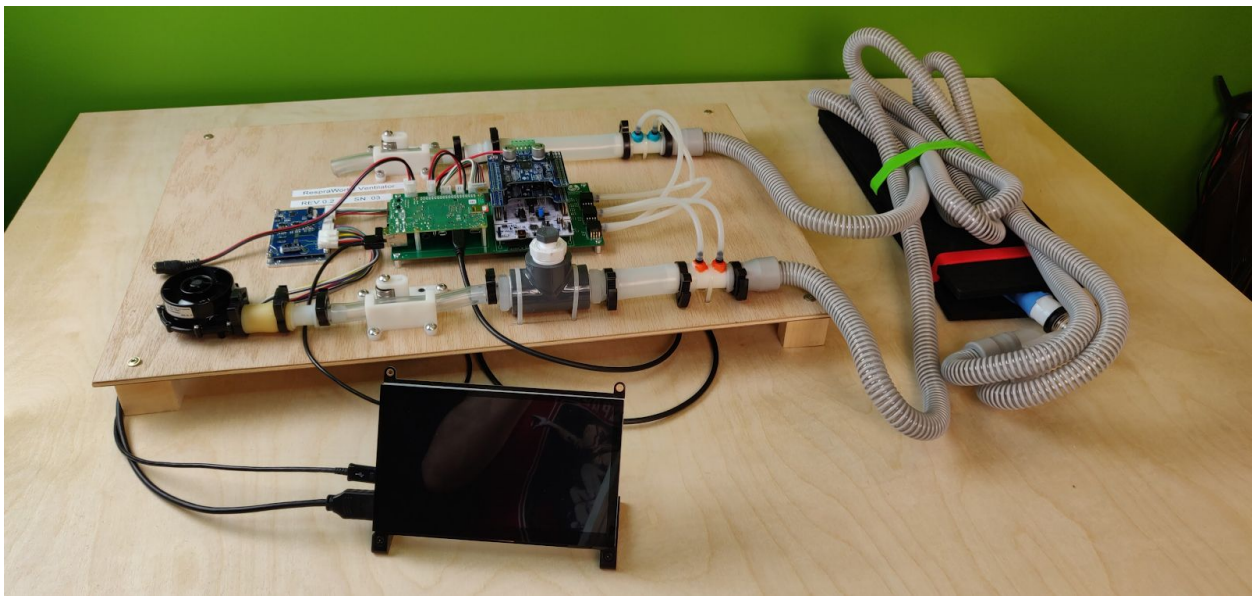
between the Pi and the TOUCH+5V connector on the Touchscreen.



G. Connect power cable

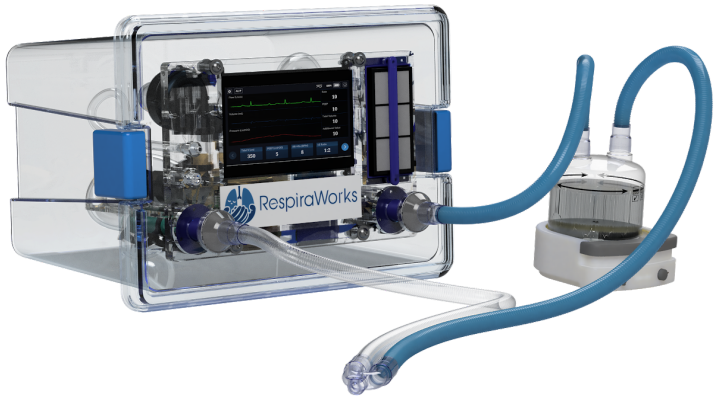
The PCB must be powered in order for the Nucleo to program correctly. A power cable which plugs into the upper left corner of the PCB is provided with the board and allows it to be powered from any 12V, 1.2A or greater power adapter with a 5.5x2.1mm center-positive barrel jack.

With this, the table-top ventilator prototype is complete:

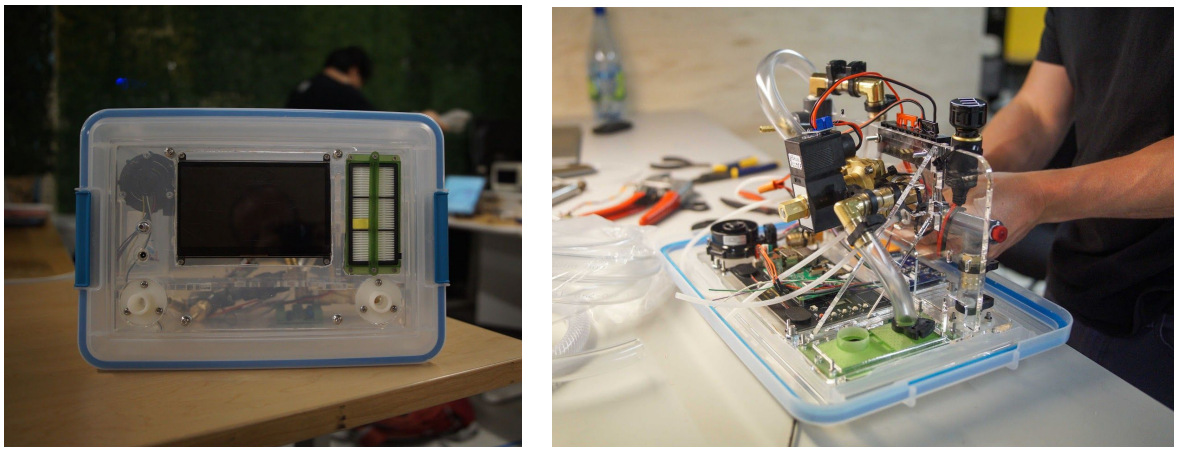


I. Assemble within enclosure (future)

These components are intended to be assembled into a rugged sheet metal enclosure for the final mechanical design. The compact version of the ventilator assembly and packaging strategy has already gone through several iterations, including an Alpha Build device which proved out the use of a detachable internal structure for ease of assembly.



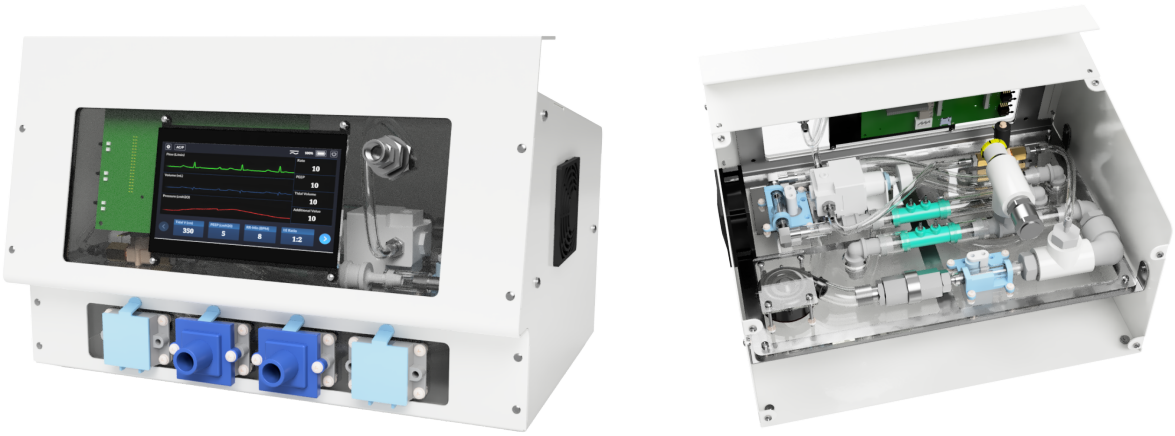
Earlier design, using the Alpha Build packaging concept



Alpha Build prototype assembled (left) and open (right)

The next iteration of this build will demonstrate the packaging in the production housing, which has been designed but not yet constructed. Based on lessons learned from the Alpha Build prototyping process, the ventilator will use a detachable internal assembly, to which all

pneumatic components can be mounted and connected. This allows for 360 degree accessibility to components during initial assembly. When complete, this internal assembly is bolted into the enclosure, and the enclosure is screwed shut. The top-rear positioning of the removable enclosure lid provides access to components that will need routine maintenance.



Left: Packaged production ventilator assembly, Right: back panel removed

Further aspects of the production packaged design are detailed in the first section of 03-03 Assembly Video[8].

[8] Also can be viewed at https://youtu.be/2hdV5CWcLb4