Bernoulli Flow Sensor

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Motivation

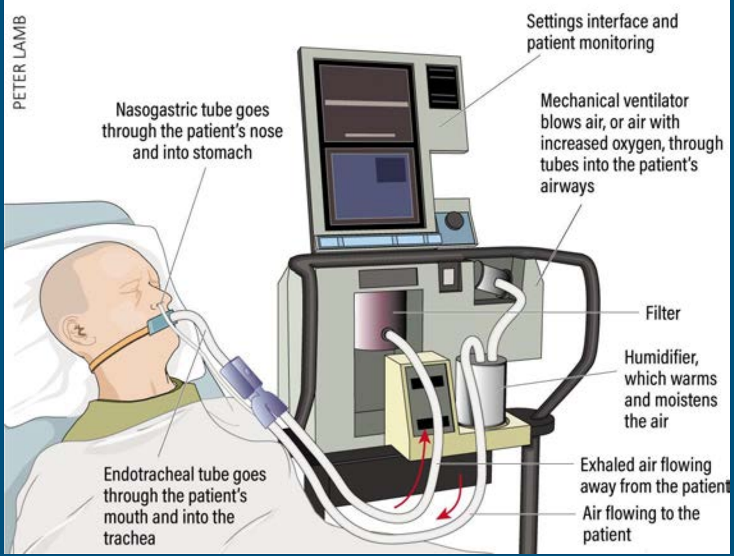


Figure 1. Mechanical ventilator for positive pressure ventilation

Elliot, Z. (2018) “An overview of mechanical ventilation in the intensive care unit”, *NursingStandard*

- Certain respiratory issues are treated with mechanical ventilation

- A machine connected to the patient’s airways pushes oxygen in and removes carbon dioxide

-US has 20.5 ventilators per 100,000 residents

-10 African countries have no ventilators

-Strain on resources necessitates the splitting of ventilators

-Can we make this process safer and more efficient by monitoring airflow rates?

Goals and Considerations

- Create a low-cost device that can be inserted into the mechanical ventilator lines to measure flow rate
- Use inexpensive materials to prototype: Arduino and 3D printed tube and support
- Can be mass-produced if prototype proves viable
- No moving parts
- Easy to sanitize and implement
- Quick measurement rate
- Self-contained
- Lasts over the duration of treatment

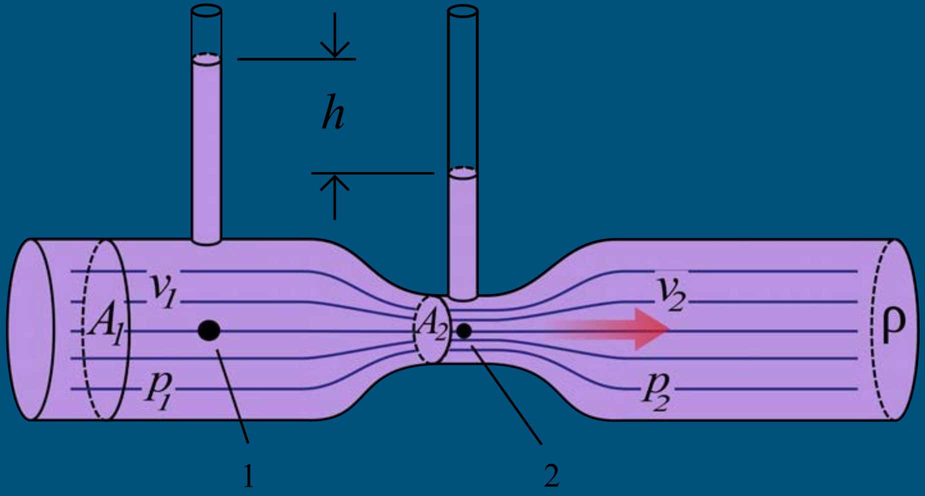
Method

Indirectly measure flow rate by measuring pressure at specific points.

-Pressure sensors with high resolution are readily available

-We can use Bernoulli’s principle to relate an intentional pressure difference to differences in air velocity

-Air velocity can be used to calculate volume flow rate



Physical Background

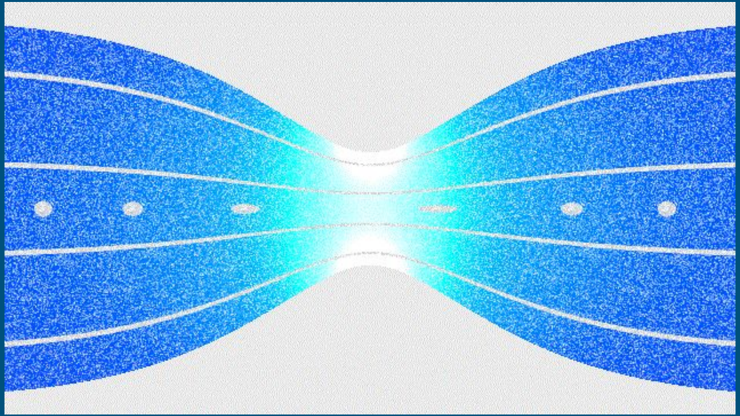
$$P_1 + \frac{1}{2}\rho v_1^2 = P_2 + \frac{1}{2}\rho v_2^2$$

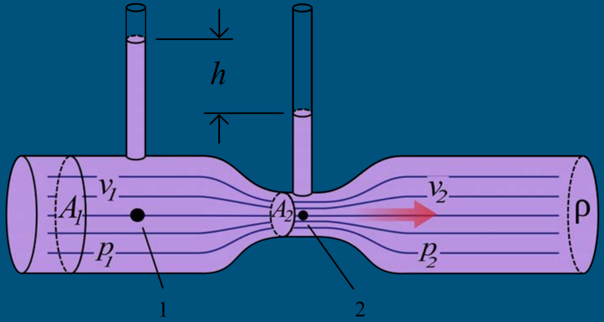
$$v_i = \frac{Q}{A_i}$$

$$Q = \sqrt{\frac{2\Delta P}{\rho\left(\frac{1}{A_2^2} - \frac{1}{A_1^2}\right)}}$$

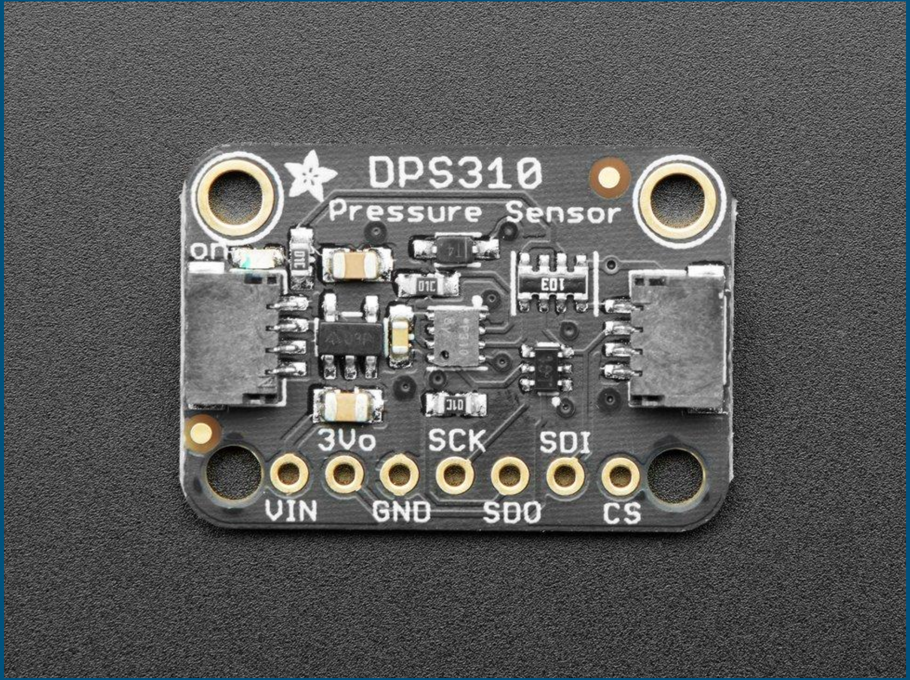
-Mass, energy, and momentum are conserved if a fluid flows from point with a cross-sectional area A1 to one with A2

-As it is compressed, the velocity increases, but the total energy is conserved, so the pressure decreases.





DPS 310



-Cost: ~$5-$8 depending on retailer and quantity

-Supported Protocols: I2C and SPI

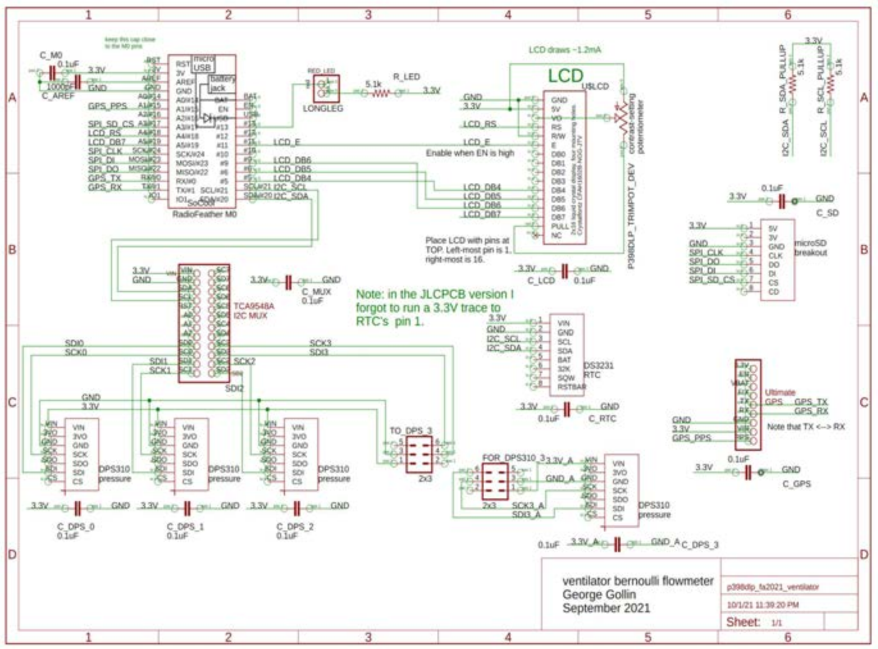
-Working environment: 300 - 1200 hPa and -40 to 85°C

-Resolution: ±0.002 hPa (±2 cm) and ±1 hPa absolute accuracy (8m)

-Dimensions: 25.5mm x 17.7mm x 4.6mm

-External reference sensor, an input sensor, a throat (constriction sensor), and an outflow sensor

Hardware and DAC



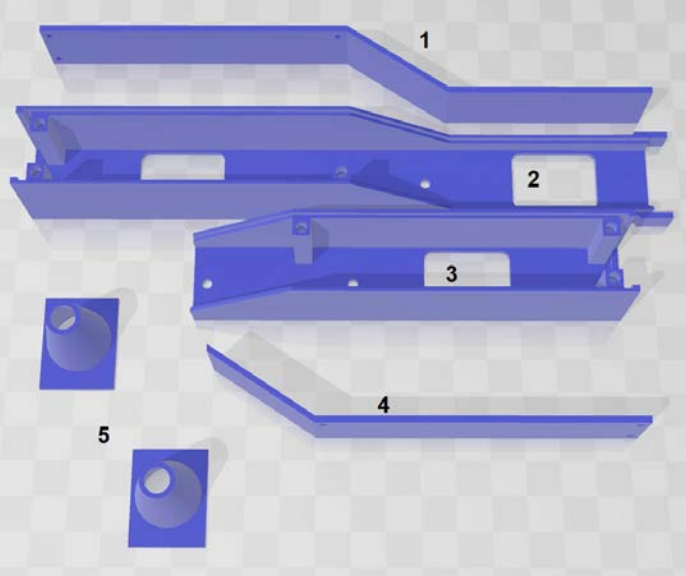
-Typical I2C setup requires SDA (data) and SCL (clock lines)

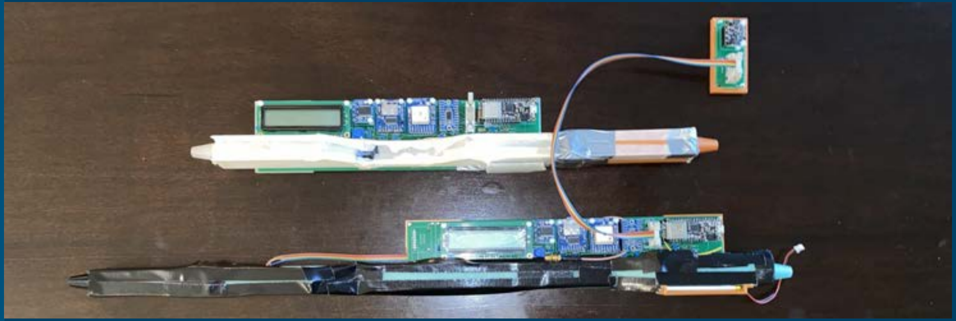
-Measurements stored to microSD card via microSD breakout

-DAC allowed us to change the frequency of measurements and number of measurements

-Because the DPS's share an I2C address, a TCA9548A I2C multiplexer was used.

Tube Design





The disassembled insert. Pictured top: (1) first half of lid, (2) first half of tube, (3) second half of tube, (4) second half of lid, (5) nozzles for attaching vinyl tubing. Rectangular holes in the tube serve as locations for the DPS310 units. Each grid square is 10 mm on a side.
Bottom: Two tubes with a diffuser, and one with an extender in the middle.

Data Collection

-Commercial pump used to create airflow

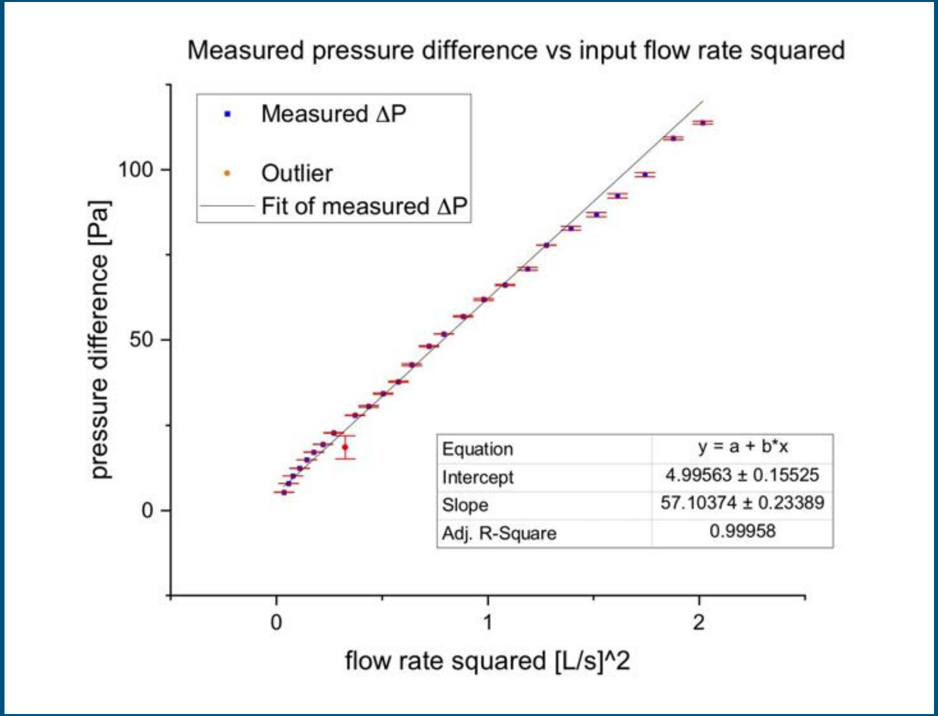
-Ball valve used to adjust flow rate

-Commercial flow meter used as reference

-Two stages of data collection: measuring pressure offsets between sensors (no flow) and measuring pressure values with flow

-Adjustable number of samples collected each time

Calibration Curve



Equation	y = a + b*x
Intercept	4.99563 ± 0.15525
Slope	57.10374 ± 0.23389
Adj. R-Square	0.99958

-The pressure difference between the input and constriction should be a constant multiple of the square of the flow rate. This value should be 58.08 Pa•s^2•L^-2.

-There should be no intercept

-Curves away from the line at higher and lower flow rates

-How can we explain the difference?

Important Considerations

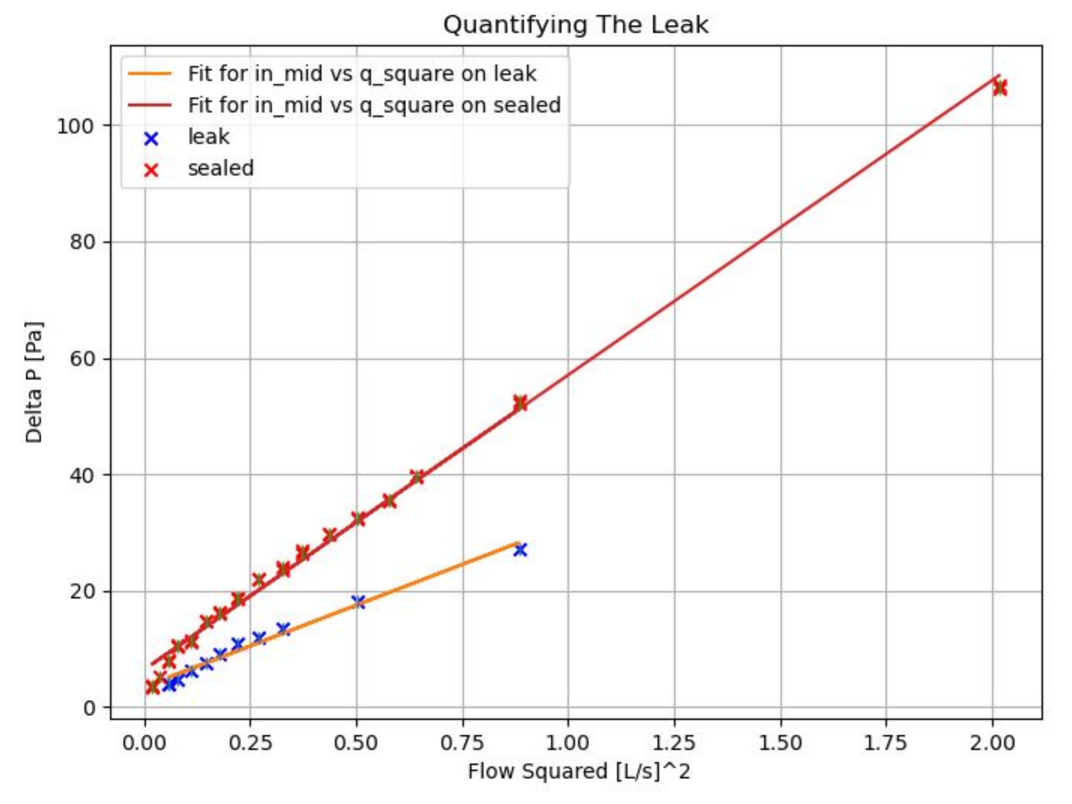
-Could turbulent flow give us faulty measurements?

-Does the interaction between the walls and the air create resistance?

-Is there leakage from the device?

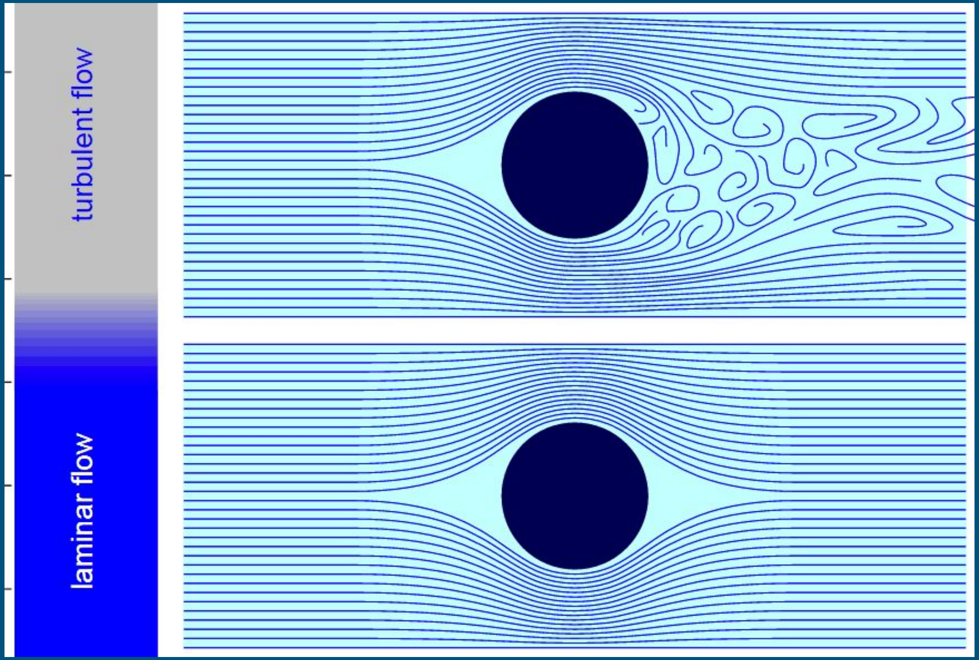
The effects of leakage

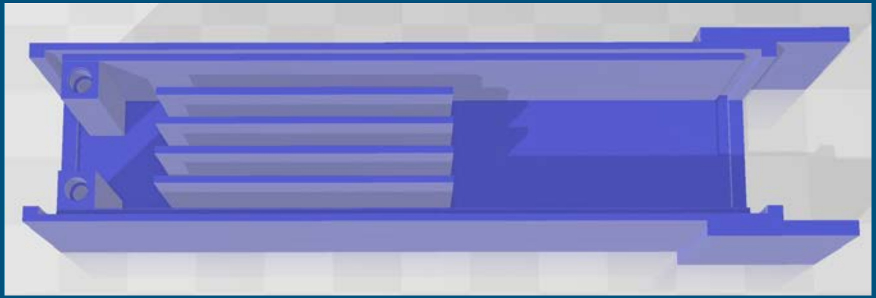
- Our final design was tested before and after the joints were taped and glued to seal leaks
- We compared the two results in the following plot.
- The line of the fit with the leak (orange) has a slope of 28.030, and an intercept of 3.4596.
- The line of the fit without the leak (red) has a slope of 50.64, and an intercept of 6.41.
- Leakage decreases the measured pressure difference.



Turbulent Flow

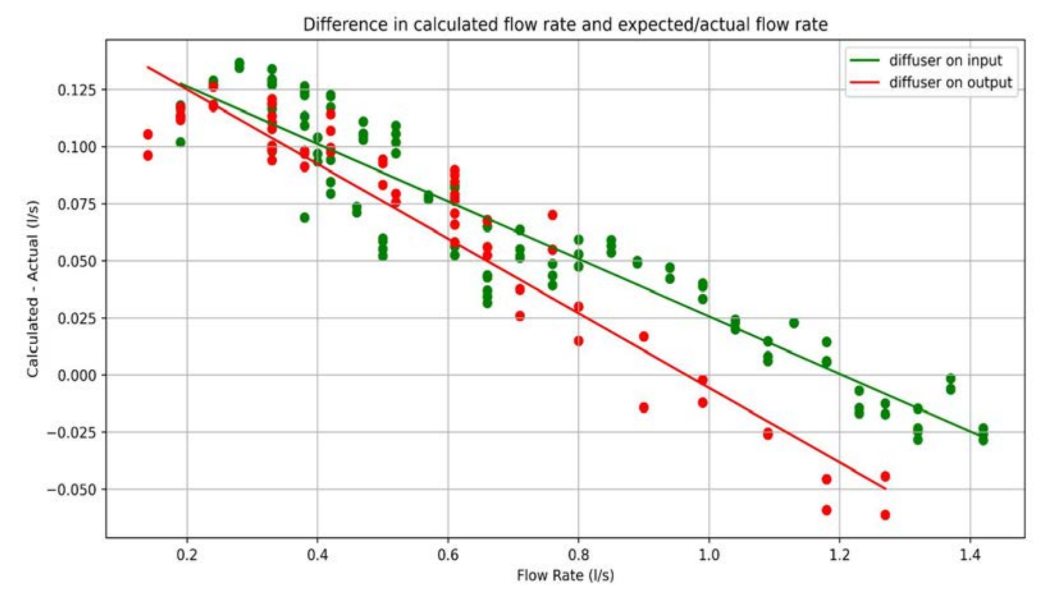
- Chaotic, unpredictable flow that differs from laminar flow, in which the fluid flows in parallel layers
- By creating a diffuser (bottom), we wanted to see if it made a difference on the observed values
- Top Image (Nuclear Power)





Turbulent Flow Results

- A diffuser was placed on the input an attempt to create a more laminar flow
- For most of the range, the diffuser on the output produced results closer to the expected flow rate.
- The diffuser on input results in a flatter trendline, meaning that locally changing the flow rate does not change the difference from the expected value as much.



Conclusions

- We were able to show that Bernoulli's principle can be applied to measure airflow at flow rates around human respiration from the high R-square value of the fit.
- The inexpensive plastic, sensors, and microcontroller mean it can potentially be implemented in a healthcare setting.
- More data and experiments needed to determine effect of turbulence and resistance