Introduction

This venturi flow sensor was designed to measure the flow rate of an air-oxygen mixture in a rapidly manufacturable ventilator produced at Brown University. It is designed to be printed on a high resolution 3D printer out of biocompatible, autoclavable medium, like Form Lab's 'Surgical Guide' resin. The venturi has barbs on its inlet and outlet so that it can be placed inline with $\frac{3}{4}$ inch ID Tygon tubing. A pressure differential is generated across the two barbed pressure taps on the top of the device, which is proportional to the flow rate through the venturi:

$$Q = \frac{C_0 A_0}{\rho\sqrt{1-\beta^4}}\sqrt{2\Delta P}$$

where Q is the flow rate through the device, P is the pressure differential between the ports, C_0 is the discharge coefficient of the venturi, A_0 is the throat area, ρ is the mass density of the airflow, and β is the ratio of inlet ID to throat ID. Figure 1 shows a technical schematic of the venturi.

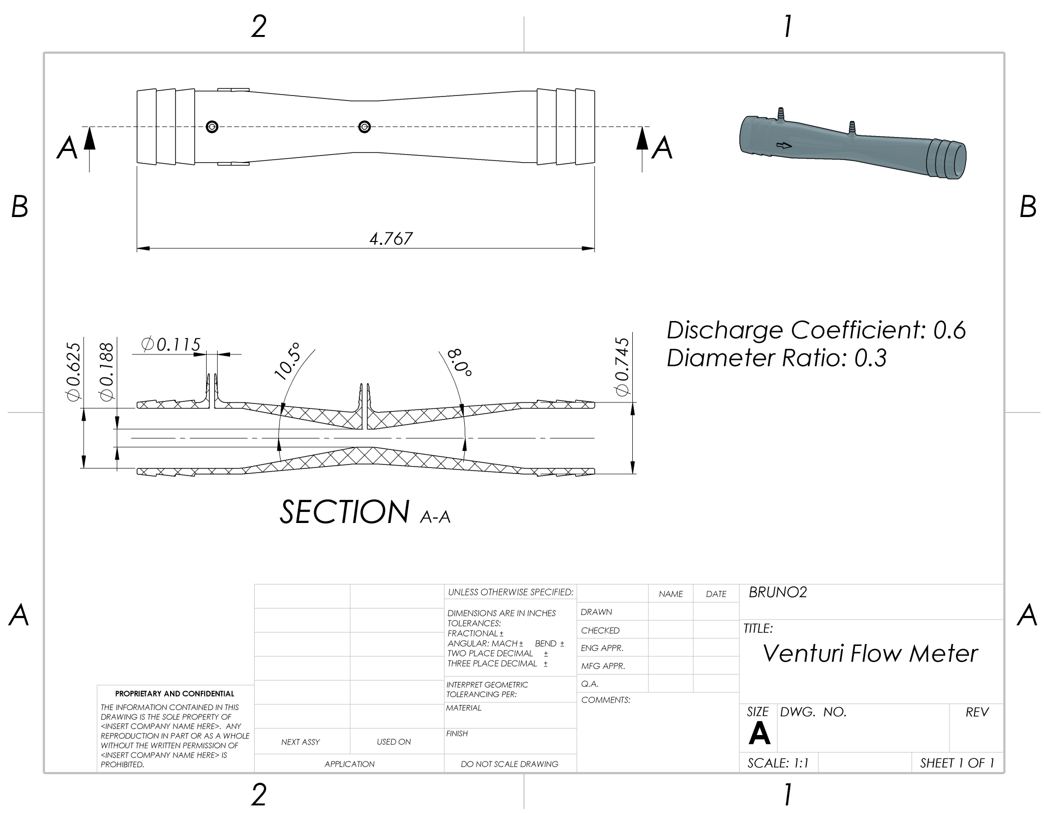

Figure 1: schematic of venturi flow meter

Design Process

The main considerations for the design of this sensor was the pressure differential that would be created in the relevant flow rate range of the system, which in the case of the ventilator is 0 - 1.5 LPS. It was found that 6 kPa differential pressure sensors could be used elsewhere in the system for absolute line pressure measurements, so this venturi is designed to not exceed 6 kPa at 1.5 LPS of flow. The pressure differential

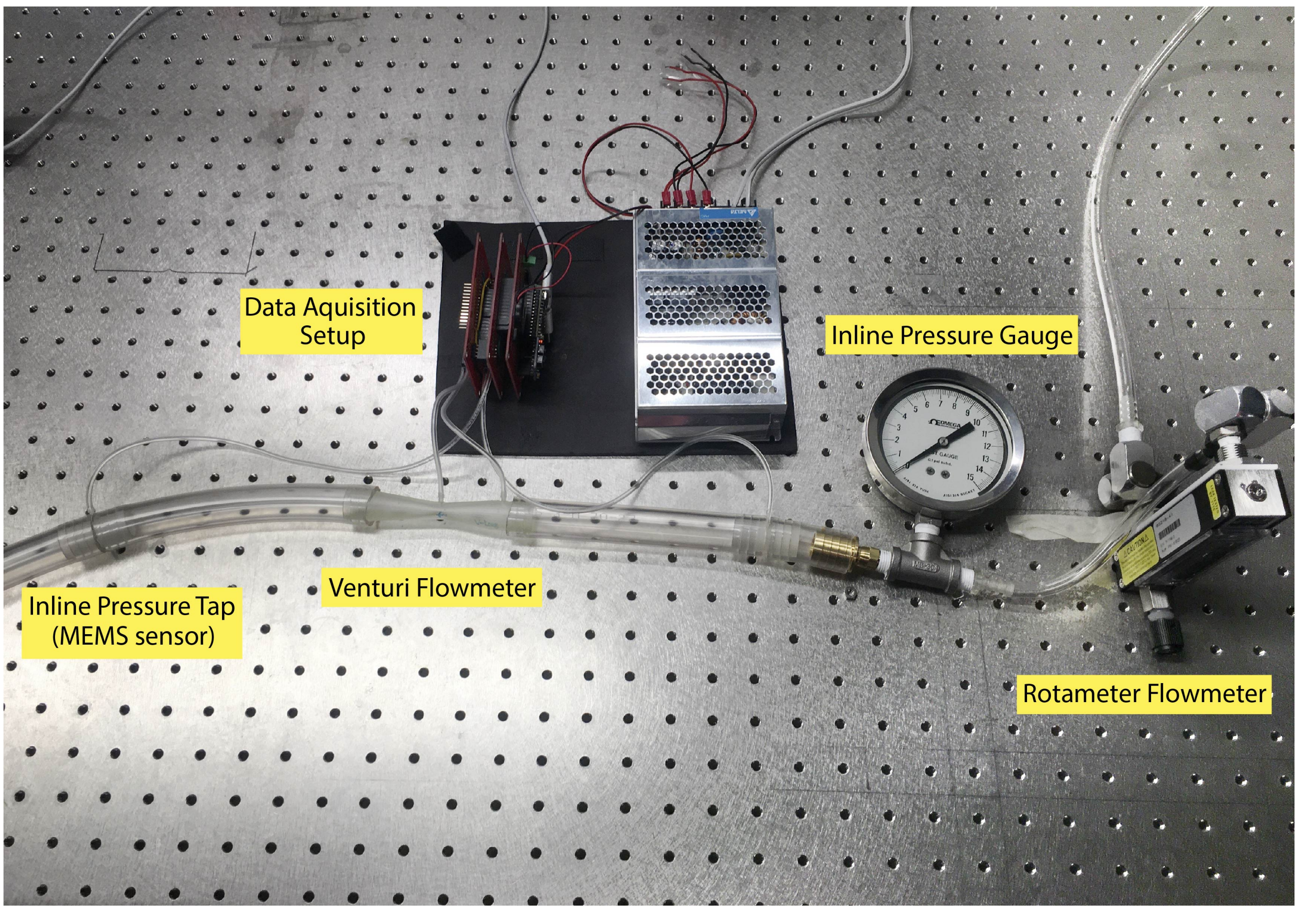

Figure 2: test set up for determining venturi dischrage coefficient

that is developed is related to the flow rate, density of the gas, and the geometry of the venturi. The diameter ratio β (the ratio between the inlet ID and the throat ID) has a large effect of the pressure differential that is developed, and could be tuned if another pressure range was desired. It is worth noting that reducing β below 0.2 will cause high head losses over the sensor, which is not desirable. To mitigate head loss over the sensor, shallower contraction and expansion angles were adopted over the course of the development of this sensor. We found that reducing the angle of the expansion angle from 15 degrees to 8 degrees had a large effect on the head loss of the sensor.

Testing

The discharge coefficient, C0, was determined experimentally using a rotameter flow meter as a calibration instrument (Cole Parmer item #: 03218-41). High pressure air from a compressor was regulated down to 25 PSI and passed through the rotameter, which throttled the flow rate down to a range of 0 - 58.5 LPM with an accuracy of ± 1.17 LPM. Flow through the rotameter was correlated to a pressure differential between the venturi ports for increments of 5 LPM between 0 and 58.5 LPM. The parameter C_0 was adjusted from a theoretical value of 0.9 to 0.6 in the governing equation to fit the results of the calibration study. An image of the experimental set up is shown in figure 2, and the pressure differential - flow rate curves are shown in figure 3.

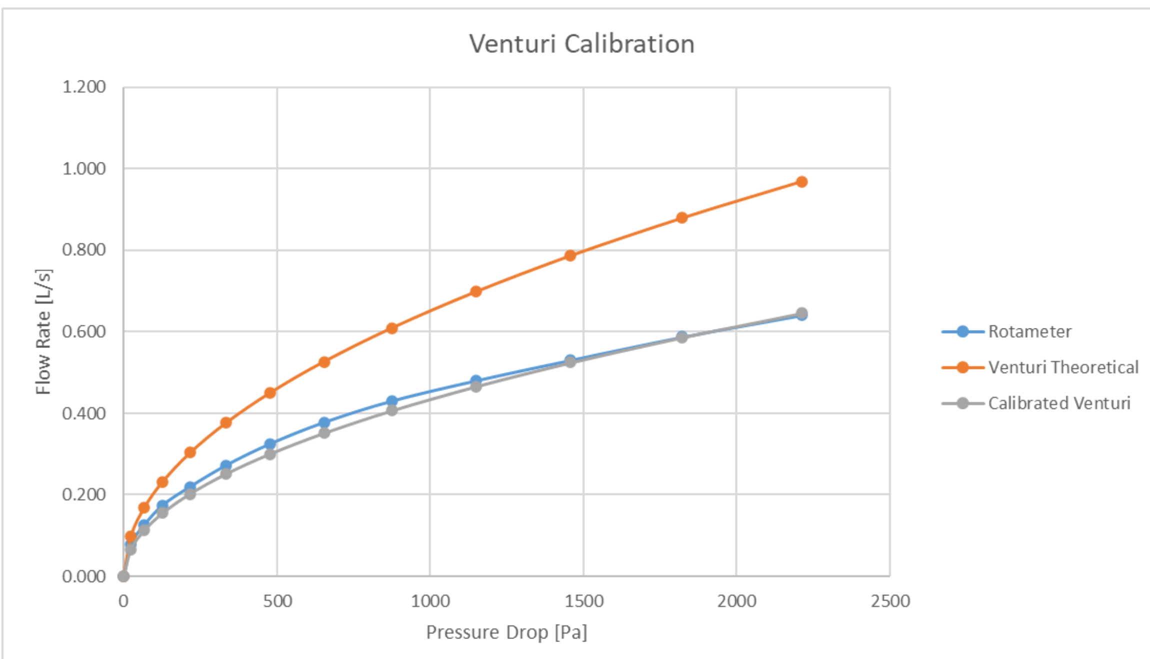

Figure 3: plot of flow rate vs pressure differential, used to calibrate the venturi flow sensor