Project Description:

The intent here is to create a monitoring device, based on a mass airflow meter, that can be used when splitting a ventilator into two or more patients. This will allow staff to monitor individual patients while being controlled by one device in extreme situations where the number of ventilators are not enough to handle the number of patients. The readout should be visible locally on the device and there may need to be parameters input by staff to create a safe operating range and to possibly create alarms when the system is measuring an out of range parameter.

Project requirements

**MUST HAVE**

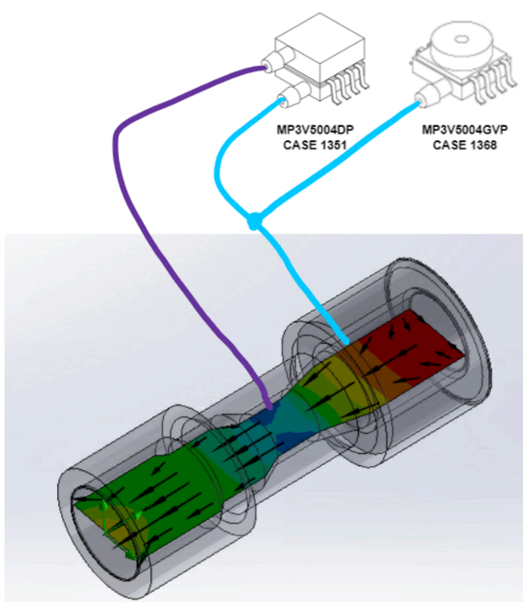
1. Inline connection on respiratory tubing, 22mm and 15mm per ISO 5356
2. Minimal air flow restriction
3. Design should handle the following maximum flow parameters
    a. Peak flow rate capable of MVV (Maximal Voluntary Ventilation) 150 l/m, see link
    b. Max measured PIP should never exceed 280mmH2O/28mBar.
4. Measure and display TV (tidal volume) in liters
    a. Requires measurement of flow rate (venturi)
    b. Requires knowledge of flow direction
        i. Direction can be sensed (extra sensor)
        ii. Can Direction be assumed, based on pressure profile?
5. Measure and display PIP (peak inspiratory pressure) aka max pressure
    a. Need to know if display should show a running average, average over last ___ seconds or value from last cycle
    b. Accuracy +/- 2 cmH2O
6. Measure and display PEEP (positive end-expiratory pressure) aka, minimum pressure
    a. Need to know if display should show a running average, average over last ___ seconds or value from last cycle
7. Humidity readout, (these will also provide pressure and temperature readings, likely at a slower update rate ~5 Hz)
8. Power requirements:
    a. Power source TBD, can it be 5V from USB?
    b. Connector TBD. Ideally should be a locking connector to avoid kick-out.
    c. Battery backup? With battery recharging circuit?
9. Device Calibration
    a. As there will be differences in 3D printed parts, calibration will be necessary prior to use.
10. Speed
    a. Readout for the differential sensor 100Hz, this value comes from reference documents.

**NICE TO HAVE**

1. Be Remote monitoring? Likely best to offer a powered data port to provide

    a. Ethernet or POE?
    b. WiFi? (note that WiFi is NOT used in medical environments)
    c. Other? RS232, 422, CANBUS, or ?
2. Ability to create audible and visible alarms
    a. Max PIP has been exceeded
        i. Need to understand if this is a constant, or needs to be set per patient: most probably a set of presets should do (e.g. kid vs. adult, or low-med-high), probably relative to atmospheric
    b. Tidal Volume out of range?
        i. Need to understand if this is a fixed max and min range, or needs to be set per patient? Or percentage of set (again 5, 10, 20% or something)
3. Measure the AirMix ratio?
4. Firmware updatable in the field (when not in use)
    a. over the air updates like in Tesla cars? really risky - requires WiFi/Eth
    b. Update over USB to laptop
5. Maybe a water trap to prevent droplets getting into lines

# Measure pressure difference for venturi flow measurement




Online calculator https://www.efunda.com/formulae/fluids/venturi_flowmeter.cfm

Regarding the flow sensor I had a long conversation with my chef engineer. He strongly suggest a MXP MP3V5004DP, this has the following reasons. No additional electronics besides a controller, works with 3.3V, temperature compensated and calibrated and a min temp drift and jitter.

Venturi calculations are showing a pressure differential of well under 1000 Pa, so tuning sensitivity to the available signal is required.

~~Option 1. Differential sensor with ± 500Pa, temperature compensation and i2C interface~~

- ~~US$18/ea @ qty 1K (low quantities stock)~~
- ~~https://www.digikey.com/product-detail/en/SDP810-500PA/1649-1074-ND/6605489~~

~~Option 2. Differential sensor with ± 2000Pa~~

- ~~US$9.48/ea @ qty 1K (~6K stock)~~
- ~~Requires op-amp signal conditioning to scale it for ADC. Calibration issues?~~
- ~~https://www.digikey.com/product-detail/en/nxp-usa-inc/MPXV7002DPT1/MPXV7002DPT1TR-ND/1168437~~
- ~~\~~

Differential pressure sensor for Venturi

- MP3V5004DP: https://www.digikey.com/products/en?keywords=MP3V5004DP
- Data Sheet: https://www.nxp.com/docs/en/data-sheet/MP3V5004G.pdf

Gauge Pressure Sensor:

- MP3V5004GP: https://www.digikey.com/product-detail/en/nxp-usa-inc/MP3V5004GP/MP3V5004GP-ND/2186181

and @Steve Glow has another similar sensor for gauge pressure.

# Measure pressure of flow for PIP/PEEP

This sensor needs to be able to measure 28mBar, but with headroom, should be no greater than 4kPa.

Option1 (3.92kPa) Vented Gauge sensor

- US$9.62/ea @ qty 1K
- https://www.digikey.com/product-detail/en/nxp-usa-inc/MPXV5004GC6T1/MPXV5004GC6T1TR-ND/951843

**AirTemp, Humidity**

We should also measure the air temp and humidity, to use the values for recalculating the airflow and AirMix ratios. Also to control and check the air temp and humidity for the medical professional.

We selected 2 different sensors as base, both of them are the same and can be substituted. Digikey have >10k in stock.

Chips

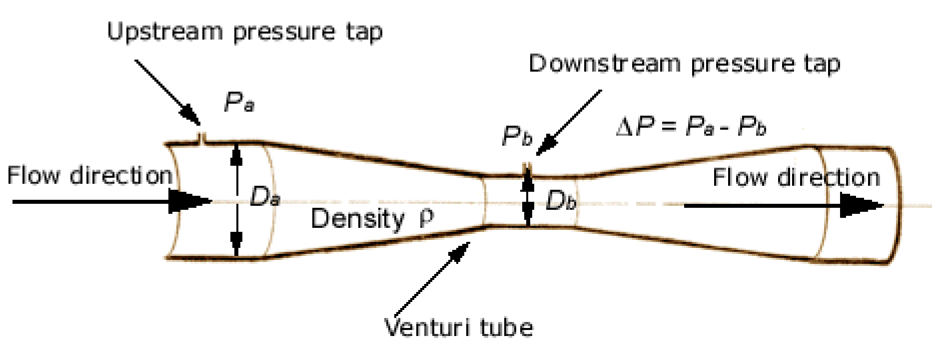
| | |
|---|---|
| HDC2010 | https://www.ti.com/product/HDC2010?utm_source=google&utm_medium=cpc&utm_campaign=asc-null-null-gpn_en-cpc-pf-google-eu&utm_content=hdc2010&ds_k=HDC2010&dcm=yes&gclid=CjwKCAjwsMzzBRACEiwAx4lLG3VleX-qH3Dw6sjD0gmG3DmaI99McLxbbcDelWVuu1EhpYeh-AYZMhoClJQQAvD_BwE&gclsrc=aw.ds |
| SHTC3 | https://www.mouser.com/datasheet/2/682/Sensirion_Humidity_Sensors_SHT3x_Datasheet_digital-971521.pdf |

**Flow Direction**

To determine the airflow direction

- Option 1. Using a heating element and 2 temperature sensors
- Option 2. Add a 3rd pressure sensor on the other end of the venturi, pressure will be dropped as the flow goes thru the venturi
- Option 3. If not using a venturi, use two gauge pressure sensors on either side of a pressure drop to determine direction

Basic Mathematics



## Equations used in the Calculation

As long as the fluid speed is sufficiently subsonic ($V$ < mach 0.3), the incompressible Bernoulli's equation describes the flow. Applying this equation to a streamline traveling down the axis of the horizontal tube gives,

$$p_a - p_b = \Delta p = \frac{1}{2}\rho V_b{}^2 - \frac{1}{2}\rho V_a{}^2$$

From continuity, the throat velocity $V_b$ can be substituted out of the above equation to give,

$$\Delta p = \frac{1}{2}\rho V_a{}^2 \left[ \left( \frac{A_a}{A_b} \right)^2 - 1 \right]$$

Solving for the upstream velocity $V_a$ and multiplying by the cross-sectional area $A_a$ gives the volumetric flowrate $Q$,

$$Q = \sqrt{\frac{2\Delta p}{\rho}} \frac{A_a}{\sqrt{\left( \frac{A_a}{A_b} \right)^2 - 1}}$$

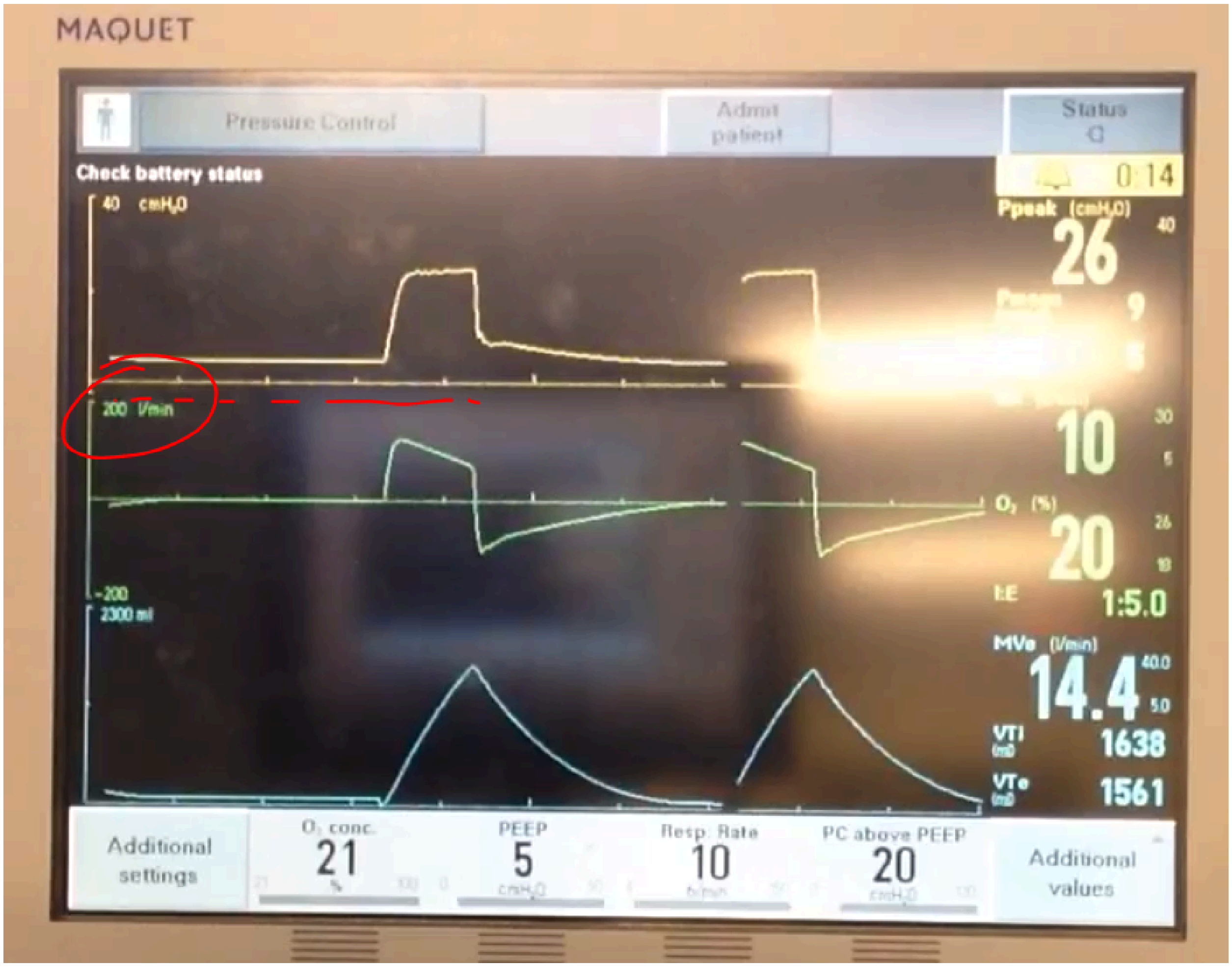
Ideal, inviscid fluids would obey the above equation. The small amounts of energy converted into heat within viscous boundary layers tend to lower the actual velocity of real fluids somewhat. A **discharge coefficient *C*** is typically introduced to account for the viscosity of fluids,

$$Q = C\sqrt{\frac{2\Delta p}{\rho}}\frac{A_a}{\sqrt{\left(\frac{A_a}{A_b}\right)^2 - 1}}$$

*C* is found to depend on the Reynolds Number of the flow, and usually lies between 0.90 and 0.98 for smoothly tapering venturis.

The mass flowrate can be found by multiplying *Q* with the fluid density,

$$Q_{mass} = \rho Q$$




# Sensors for flow using hot wire method

- Automotive sensor - 1000s available $65 locally at auto shops, $20 via aliexpress
- PCB mounted sensor - By Degree C Controls $85/each qty(100) available now
- PCB mounted sensor (not temperature compensated) east coast MFG, 500 in 2 weeks
- PCB mounted sensor (temperature compensated) east coast MFG, 500 in 2 weeks
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# U-tube Manometer (should be moved to other channel?)

https://www.engineeringtoolbox.com/u-tube-manometer-d_611.html
Needs to be upright otherwise vertical offset not measured correctly
https://www.thingiverse.com/thing:1205032

NXP Spirometer Demo