ACCESSIBLE VENTILATOR DESIGN CONCEPT

- **Introduction**

  The recent outbreak of the COVID 19 pandemic has compromised the health care system around the world. The positive cases have outnumbered the medical facilities that any hospital can provide of which ventilators are of major concern as they can be a major life saving instrument for a patient suffering from Acute respiratory distress syndrome (ARDS) seen in the COVID 19 positive cases.

- **Problem Statement**

  Due to the strict lockdown all over the country to prevent the further spread of COVID 19, has led to a shutdown of all the manufacturing plants and transportation systems. This has restricted the manufacturing of ventilators which further worsens the acute shortage of the ventilators.

  Ventilator is a complex machine engineered with numerous parts that have to be sourced from different places, and hence can be made in a proper manufacturing setup with all the resources only.

- **Objective**

  To design a ventilator that is easy, fast and cost efficient to manufacture with minimum resources without compromising the basic protocols of a ARDS requirement.

- **Solution**

  Developed a conceptual ventilator design that exhibits the following features :-

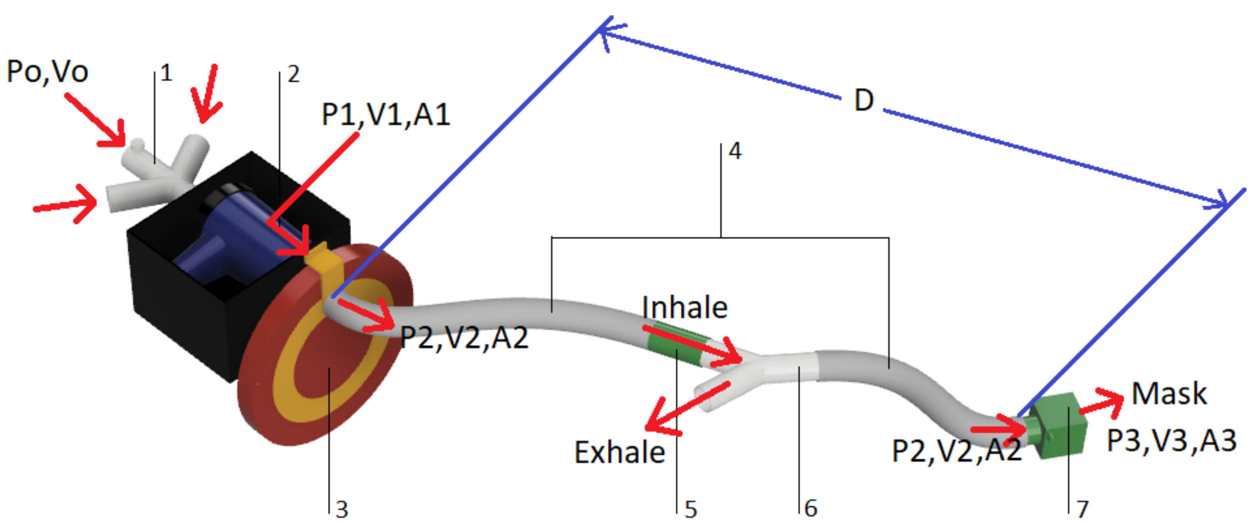
  1. The modular design allows it to function and be manufactured with any dimension in accordance to the available components (hair dryer)
  2. A very simplistic design approach that requires just a 3D printer to manufacture parts and no prior knowledge for its assembly
  3. Requires most widely available components such as a hair dryer and a DC motor to function
  4. Achieves the ARDS compliant settings mechanically, hence eliminating the use and sourcing of any complex part/ sensor
  5. Can be manufactured in under 10 hrs. and assembled in under 10 minutes.
  6. Costs under Rs. 6,000

- **Scope**

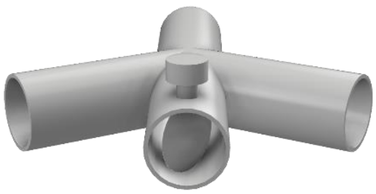
  With further research and development of this conceptual design, it can be a full-fledged solution to the ARDS complaint emergency ventilator kit to fight the acute shortage.

  Facility as accessible as a school with 3D printers can be converted into a manufacturing unit with minimum no. of workers

- **Design & Calculation**



1. **Input gas valve**



This valve allows input of different gases with freedom to adjust the input percentage of each gas individually by revolving the knob

2. **Hair dryer**

Power **"P"**, output nozzle radius **"R",** base length **"L",** input pressure **"Po"**, input velocity **"Vo"**, output pressure **"P1",** output velocity **"V1"** and density of air mixture **"p"**

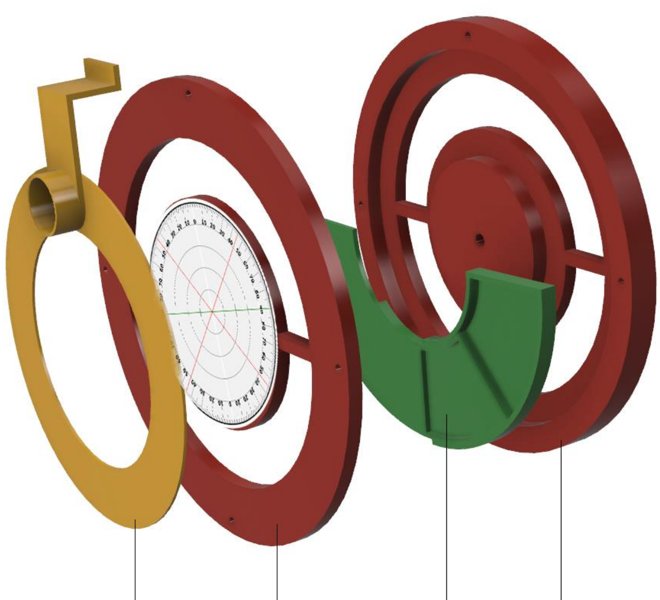
$$P = P_1 A_1 L \Rightarrow P_1 = P/A_1 L = \boxed{P/(\pi R_1^2) \cdot L}$$

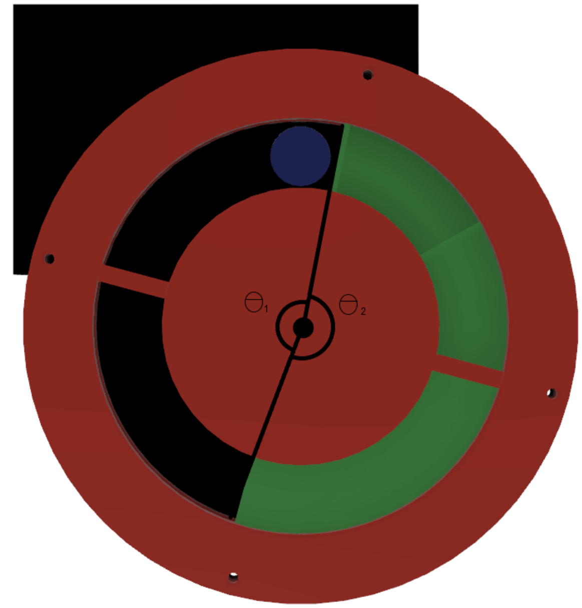
$$P_0 + \frac{1}{2}\rho V_0^2 \ (\to 0) = P_1 + \frac{1}{2}\rho V_1^2$$

$$\Rightarrow \boxed{V_1 = \sqrt{\frac{P_0 - P_1}{\frac{1}{2}\rho}}}$$

3. **Disc**

It's an assembly of 4 parts and is attached to a DC motor. It controls the breadths per minute (BPM) and exhale : inhale ratio





Part "a" is the hub attached to the motor shaft. Part "b" is a combination of 2 or more parts that can slide inside the other and this combination sits in the cavity of "a". Part "c" covers the hub "a" with a 360-degree scale over it. Part "d" sits inside the cavity of "c" without making any contact and is fixed with the hair dryer holder. Further a pipe is connected to part "d".

Part "b" covers "**ϴ2**" degrees in the disc while the empty space covers "**ϴ1**" degrees. We can increase "ϴ2" angle by sliding the parts of "b" while measuring it on the 360-degree scale on part "c". Part "a, b, c" rotate together while part "d" stays stationary. Therefore, by setting appropriate angles "ϴ1 and ϴ2" we can vary the time for the air sucked by hair dryer that can be thrown out through empty space (for inhale) or be blocked by part "b" (during exhale), as follows :-

"b" is BPM, **"x : y"** is exhale : inhale ratio, **"N"** is rpm of DC motor, **"D"** is distance between part "d" and part "7" (i.e., total length of the pipe used), **" t' "** is the time taken for air to travel "D", **"t1"** is time airway of dryer is open, **"t2"** is the time airway of dryer is blocked, **"P2"** is the pressure of air in pipes (part "4"), **"V2"** is velocity of air in pipes (part "4") and **"R2"** is the radius of pipe (part "4").

$$V_1A_1 = V_2A_2 \Rightarrow V_2 = \frac{V_1(\pi R_1^2)}{(\pi R_2^2)}$$

$$P_1 + \frac{1}{2}\rho V_1^2 = P_2 + \frac{1}{2}\rho V_2^2 \Rightarrow P_2 = P_1 + \frac{1}{2}\rho(V_1^2 - V_2^2)$$

1 breadth takes **60/b** sec
Inhale duration = **[{y/(x+y)}*(60/b)]** and exhale duration = **[{x/(x+y)}*(60/b)]**

$$t' = D/V_2$$

$$t_1 = \left\{\left(\frac{y}{x+y}\right) * \left(\frac{60}{b}\right)\right\} + t'$$

$$t_2 = \left\{\left(\frac{x}{x+y}\right) * \left(\frac{60}{b}\right)\right\} - t'$$

Disc rotates 360-degrees in 60/N secs, so it will rotate **ϴ degrees** in 60*ϴ/ 360*N = **ϴ/6N sec**

$$\theta_1 + \theta_2 = 6N(t_1 + t_2) = 6N\left(\frac{60}{b}\right) = \frac{360N}{b}$$

$$\theta_1 + \theta_2 = 360^\circ$$

$$\therefore 360 = 360\, N/b \Rightarrow N = b$$

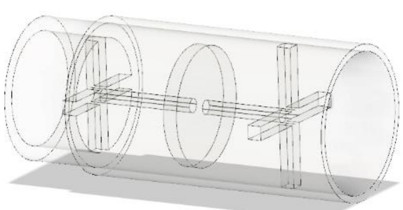
$$t = \theta/6N \Rightarrow \theta = t * 6N$$

$$\theta_1 = t_1 * 6N$$

$$\theta_2 = t_2 * 6N$$

4. **Pipes**

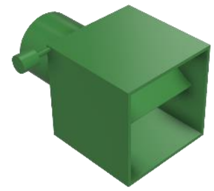
5. **One-way valve**



During inhale, the air coming from dryer pushes the circular plate towards the front end whose area is greater than the plate hence allows the air to escape while blocks the air that going towards the dryer during exhale as now the circular plate is pushed towers the back end whose area is less than the plate.

6. **2-way splitter**

7. **Pressure control valve**



"P3" is the desired pressure of the air to be inhaled by the patient, **"V3"** is the velocity of this air, **"A3"** be the projected area of the output of this valve (with length **"l"** and height **"h"**), **"Vt"** is the tidal volume and **"w"** be the weight of the patient

Calculate predicted body weight (PBW) of **Males = 50 + 2.3 [height (inches) - 60]** and
Females = 45.5 + 2.3 [height (inches) -60]

$$P_2 + \frac{1}{2}\rho V_2^2 = P_3 + \frac{1}{2}\rho V_3^2$$

$$\Rightarrow V_3 = \sqrt{\frac{P_2 - P_3}{\frac{1}{2}\rho} + V_2^2}$$

$$A_3 = \frac{V_T \times 10^{-6} \times W}{\left[\left(\frac{x}{x+y}\right)\frac{60}{b}\right] V_3} = l \times h$$

$$\therefore h = \frac{V_T \times 10^{-6} \times W}{\left[\left(\frac{x}{x+y}\right)\frac{60}{b}\right] V_3 \times l}$$

Therefore, the height "h" can be adjusted through the knob to achieve the desired pressure **"P3"**

- **Conclusion**

Based on the settings required by ARDS protocol, operator can vary the inputs such as **percentage of different gases as input, BPM, Exhale : Inhale ratio, tidal volume, PBW, final pressure (P3)** through adjusting the components by performing certain calculations step by step. An excel sheet of the same can be prepared to save calculation time in accordance to ARDS management protocol.

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