Ventilator Redesign Challenge

Ventilator Redesign proposal submitted in response to the COVID-19 pandemic

Elis Cucka
Hashir Saifullah Syed
Inzamam Haque
Hamad El Kahza

Faculty Advisor: Dr. Ziqian Dong
Degree of Bachelors of Science in the Department of Electrical and Computer Engineering
College of Engineering and Computing Sciences of New York Institute of Technology
New York NY
Date

Contents

List of Figures

Abstract

We are in the middle of a pandemic caused by COVID-19. People that get infected suffer might need a ventilator. It is the most important tool nowadays in hospitals. Lots of people are dying because they don't have access to a ventilator. The goal of this project is to redesign a low cost ventilator.

Respiratory diseases and injury-induced respiratory failure constitute a major public health problem in both developed and less developed countries. Asthma, chronic obstructive pulmonary disease and other chronic respiratory conditions are widespread. These conditions are exacerbated by air pollution, smoking, and burning of biomass for fuel, all of which are on the rise in developing countries.

Goals

- Build a ventilator which can save lives during a pandemic. use this circuit on designing a ventilator, which is the most essential device for saving lives during a pandemic.
- To develop knowledge on using Arduino in a circuit.
- To know how to prepare for a Senior Design challenge.

Ventilators need and Motivation

As the United States braces for a growing wave of patients with Covid-19 in our hospitals and ICUs, we must ensure that we have the key equipment needed to care for patients and to keep our health care workforce safe. Achieving this goal will require a concerted approach from all sectors, from local and national government to the private sector and health care providers themselves. Failure to act in a coordinated manner would keep many patients from getting the care they need and would lead to the situation we see in Italy, in which frontline clinicians are making difficult decisions about who will and who won't receive care. [RGJ20]

For some patients, breathing gets difficult enough to require medical treatment with ventilators. We are in the middle of a pandemic caused by COVID-19. According to the World Health Organization, one in six COVID-19 patients develop respiratory distress causing a breathing difficulty. The reason is the virus causes the lungs to become inflamed and filled with fluid. Doctors monitor the breath per minute experienced by patients, the figure below shows the inconsistency observed.

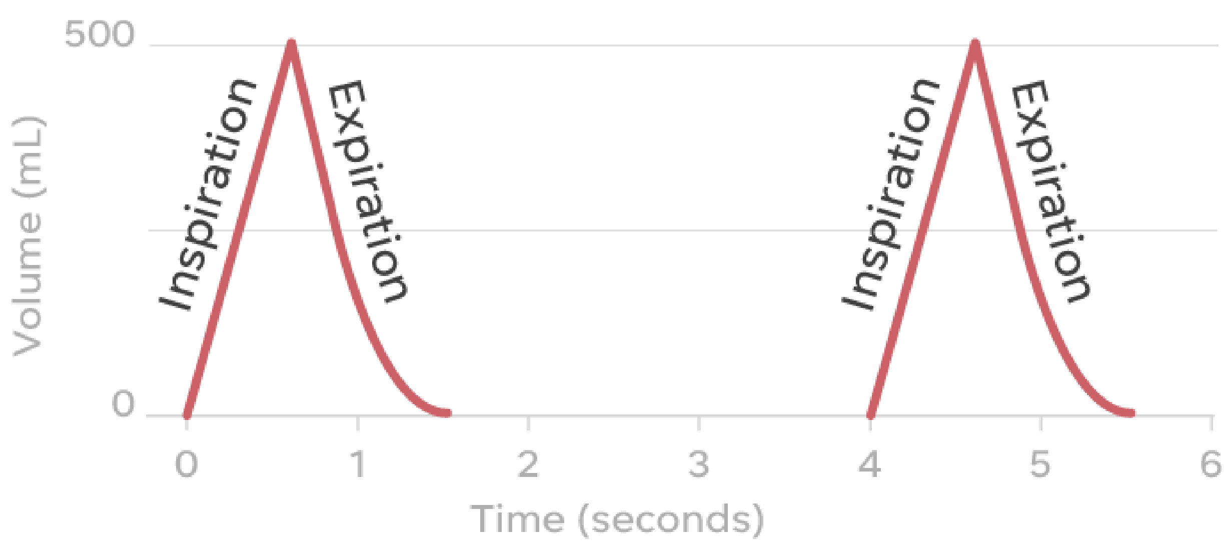


Figure 1: Breathing rates per minute

In case of respiratory illness, ventilators are needed to provide patients with a breath within a time frame to support the respiratory ability of the person. The figure below shows the breathing compensation that ventilators provide in case of lung infection.

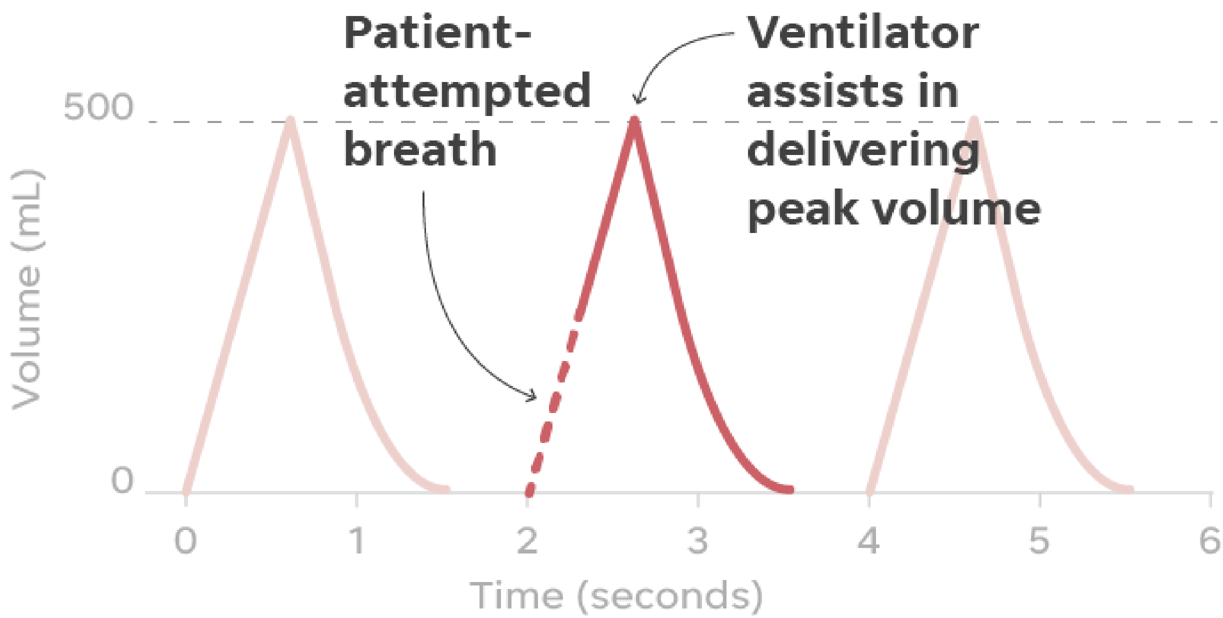


Figure 2: Ventilator breath delivery

More official sources pointed to the urgent need for ventilators. In a press conference on March 28th, Governor Cuomo stated that the price of ventilators increased from $25,000 each to $45,000, as 50 states are all in a conflict to house such critical devices. The governor also said there would be a need of more than 30,000 ventilators to meet the need of ventilators during this worsening pandemic.

In the shadow of the instrumental appeal for these devices to tackle the coronavirus; our project represents an approach to tweak the engineering of mechanical ventilators and design low cost mean models.

Objectives

- To control the speed of a DC motor, by using a gas sensor (oxygen).
- To increase the motor speed when the oxygen flow is low and decrease the speed of the motor when the oxygen flow is high.
- To develop knowledge on using Arduino in a circuit.
- To use the proper software for the simulations (Proteus Professional and Arduino IDE)

Goals

- Build a ventilator which can save lives during a pandemic. use this circuit on designing a ventilator, which is the most essential device for saving lives during a pandemic.
- To develop knowledge on using Arduino in a circuit.
- To know how to prepare for a Senior Design challenge.

Chapter 1

Design Requirements

This project has been completed in compliance with the design requirement instructed by Columbia university [Uni20].

1.1 Problem Specification

The following are key requirements:

- The automated device will squeeze a standard ambu-bag by a specified amount (about 1 to 6 inches) and at a specified frequency (10 to 30 squeezes per minute).
- The squeezing mechanism can use an arm, a lever, a piston, a belt, etc.
- Maximum pressure in the bag is typically no more than up to about 30 cmH2O.
- The Ambu-bag has an attached PEEP regulator valve that the physician can use to set the minimum exhalation pressure.
- The attending physician will set the appropriate volume and rate to maintain reasonable lung pressure as determined using a manometer.
- The size of the ambu-bags can vary slightly, so the device should be compatible with (adjustable to) to accommodate a variety of bag sizes (diam 5-7 inches).
- The device should sit firmly on a base (e.g. a plywood base).
- Assume the ambu-bag is disposable. The bag should be easy to replace without dismantling the machine.
- The device should operate reliably and continuously for multiple days at a time.
- Ideally, the device should also detect a drop of pressure in the bag, and sound a loud audible alarm. A drop of pressure indicates a possible leak in the system, or a tube or mask being disconnected. The drop in pressure can be detected in many ways. For example, if the red needle of the manometer is at the lower end of the gauge, a small color sensor can attach to the manometer and detect the position of the needle. Alternatively, a pressure sensor can measure the pressure being applied by the bag to the base. Or a potentiometer can sense the position of the servo arm, or a current detector can measure how much torque is being applied by the servo. Anything inside the tubes that comes in contact with patient air must be either disposable or serializable.

- The units will connect to a power outlet with generator backup. No battery operation is needed.
- No need to worry about contamination. Viral filters, if needed and available, will be connected by the physician to the intake and exhaust tubes.
- No need to worry about oxygenation. If needed and available, oxygen line will be connected by the physician to the bag directly.
- There is no need for the device to be sterile or sterilizable.
- Materials should be standard and minimal. If you need to fabricate specialized components (e.g. using 3D printing or laser cutting), make sure that these parts can be fabricated quickly - avoid large or long prints and cuts.

1.2 Safety

- No human testing should be performed in the initial design phase. Any future testing on humans will require IRB.
- The device should be tested first on model lungs
- Critical sensors must be duplicate/redundant if possible failure should result in an audible alarm (e.g. pressure drop due to tube disconnect)
- System failure should result in an audible alarm (e.g. pressure drop due to tube disconnect) Students may not go on Columbia campus to fabricate the device

Chapter 2

3D design models

In this section, we present the progress of our mechanical design within the time frame devoted to complete the project.

2.1 First design

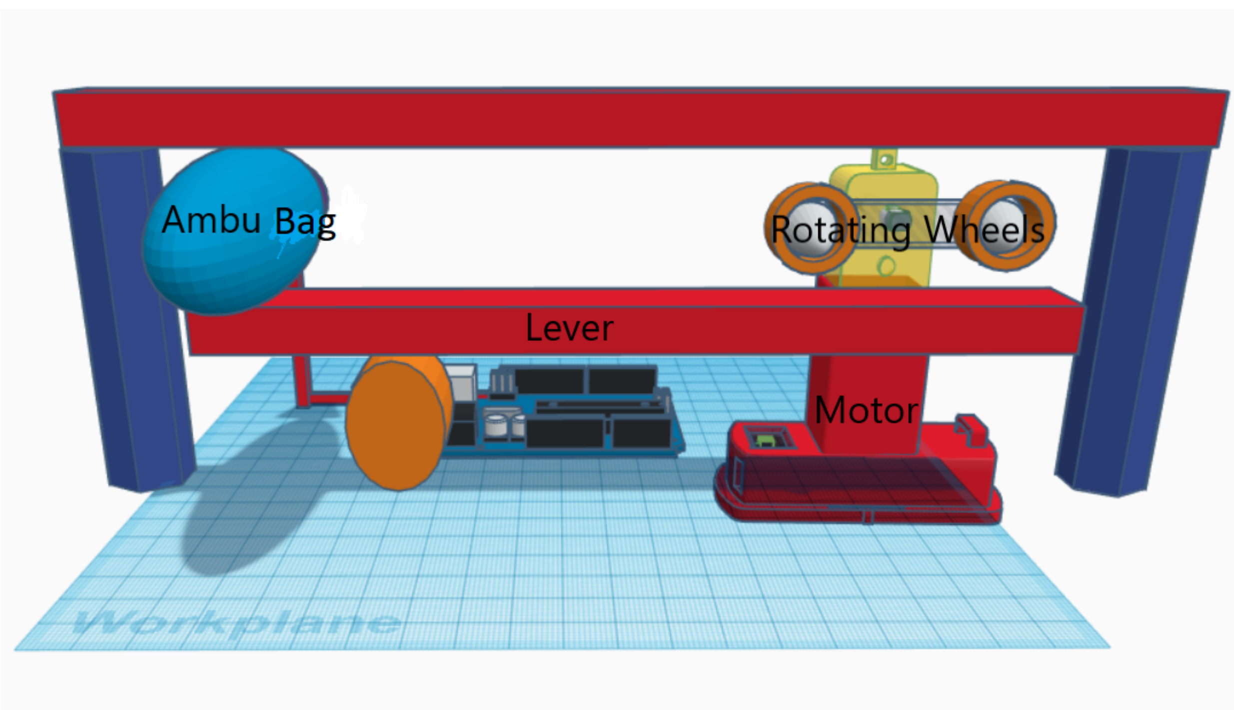


Figure 2.1: Front of 3D Design Model

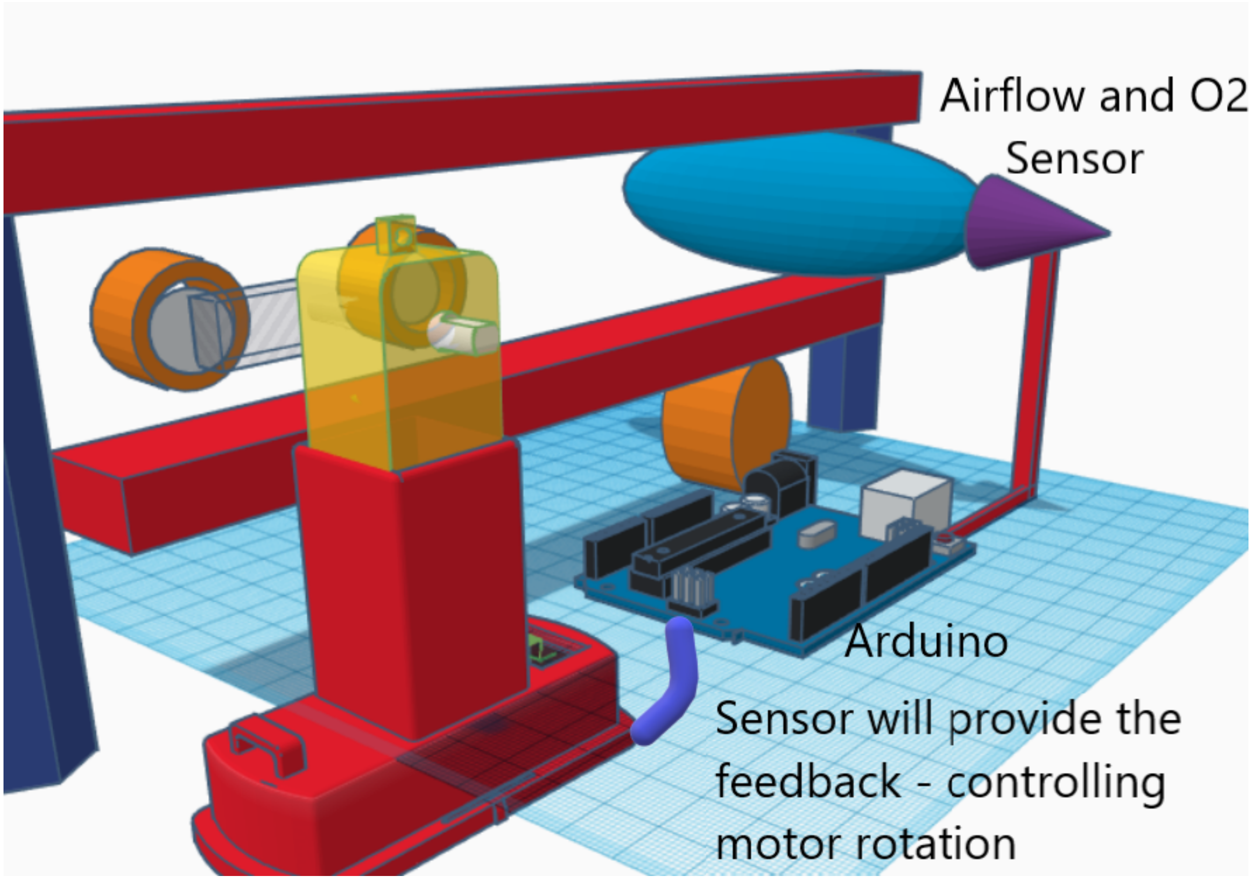


Figure 2.2: Back of 3D Design Model

In this design:

- Motor provides rotational motion.
- While the motor is working, the rotating wheels will touch the right side of the lever consequently providing a force.
- Eventually, the other side of the lever will be raised and will squeeze the Ambu bag.
- Maximum force applied on the lever when the rotating wheels are in vertical position.
- Minimum force applied on the lever when the rotating wheels are in horizontal position.
- There will be an airflow sensor for the oxygen.
- As O2 decreases, the motor will move faster and vice-versa.
- Arduino and motor-controller will provide this relationship.

2.2 Second design

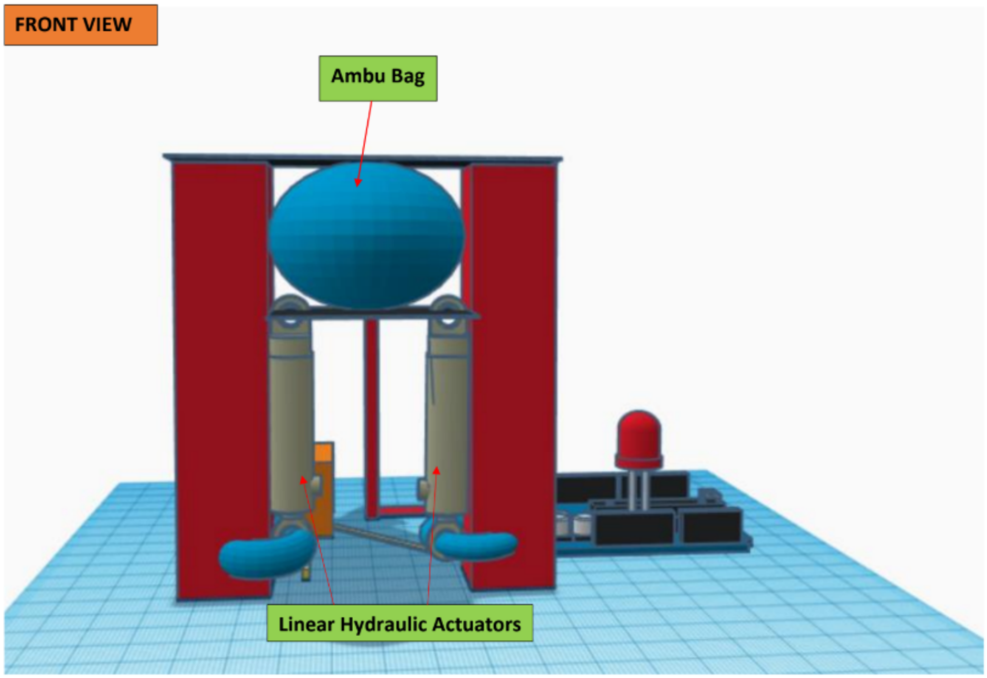


Figure 2.3: Front of 3D Design Model

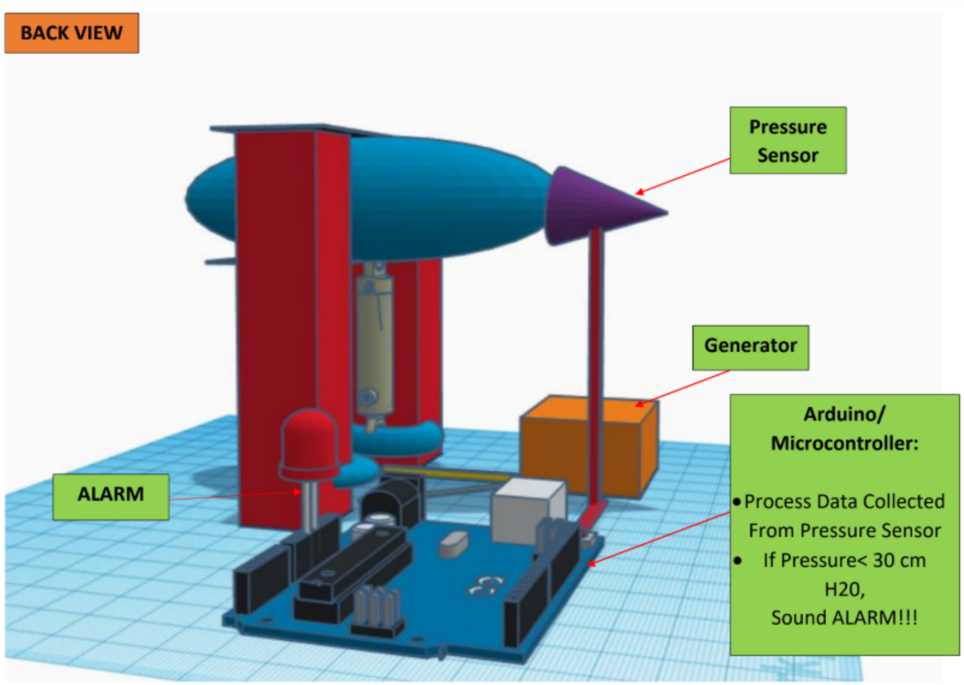


Figure 2.4: Back of 3D Design Model

- Actuator provides linear motion, which will provide squeezing of the Ambu bag.
- There will be a pressure sensor.
- If pressure is not at the right value, the Alarm will sound.
- System will be powered by a generator.

2.3 Third design

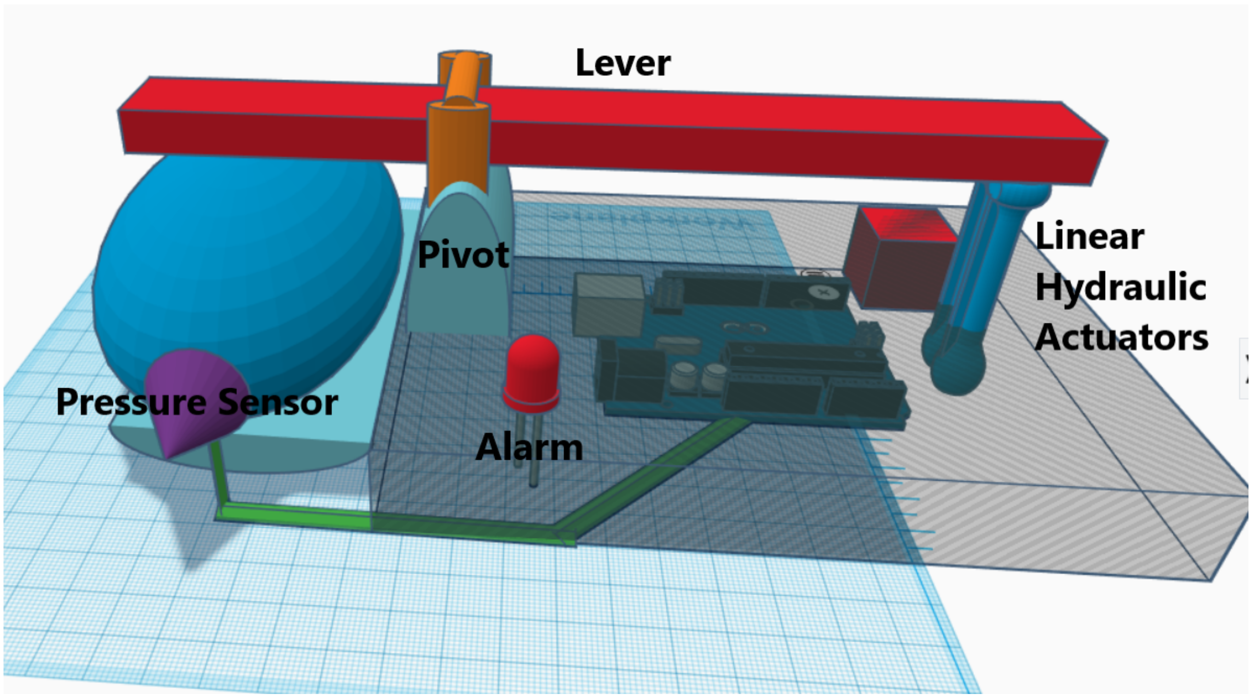


Figure 2.5: Back of 3D Design Model

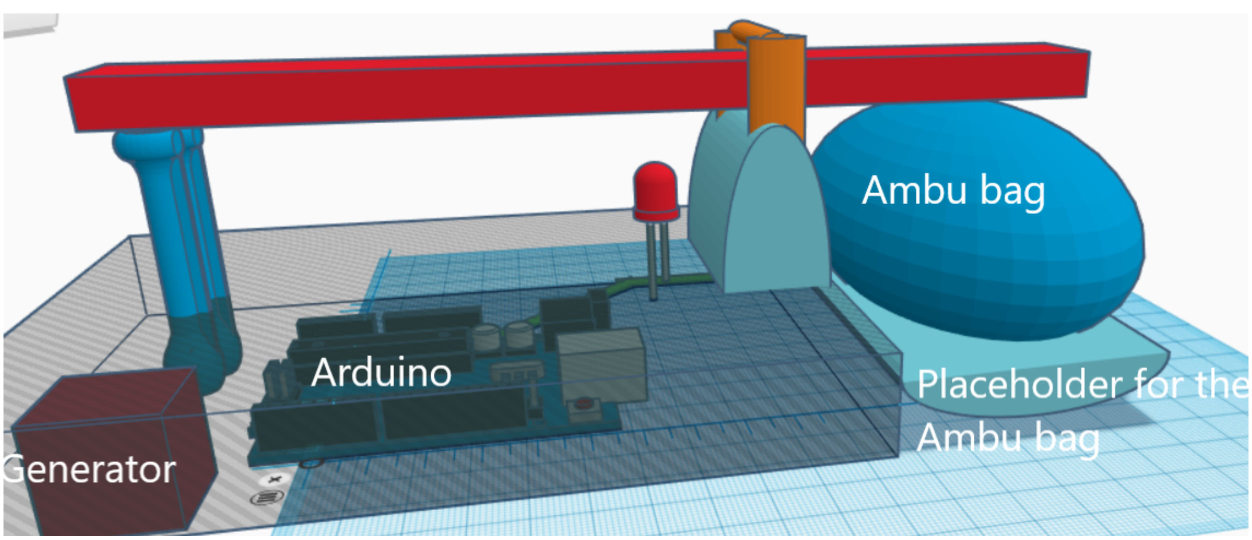


Figure 2.6: Back of 3D Design Model

- We combine our first 2 designs into one design.
- We use the principle of lever. The force will be applied on one side by 2 actuators (Assuming each has 50% duty cycle.
- If pressure is not 30 cm H20 the Alarm will sound. System will be powered by a generator.

2.4 Block Diagram and Circuitry

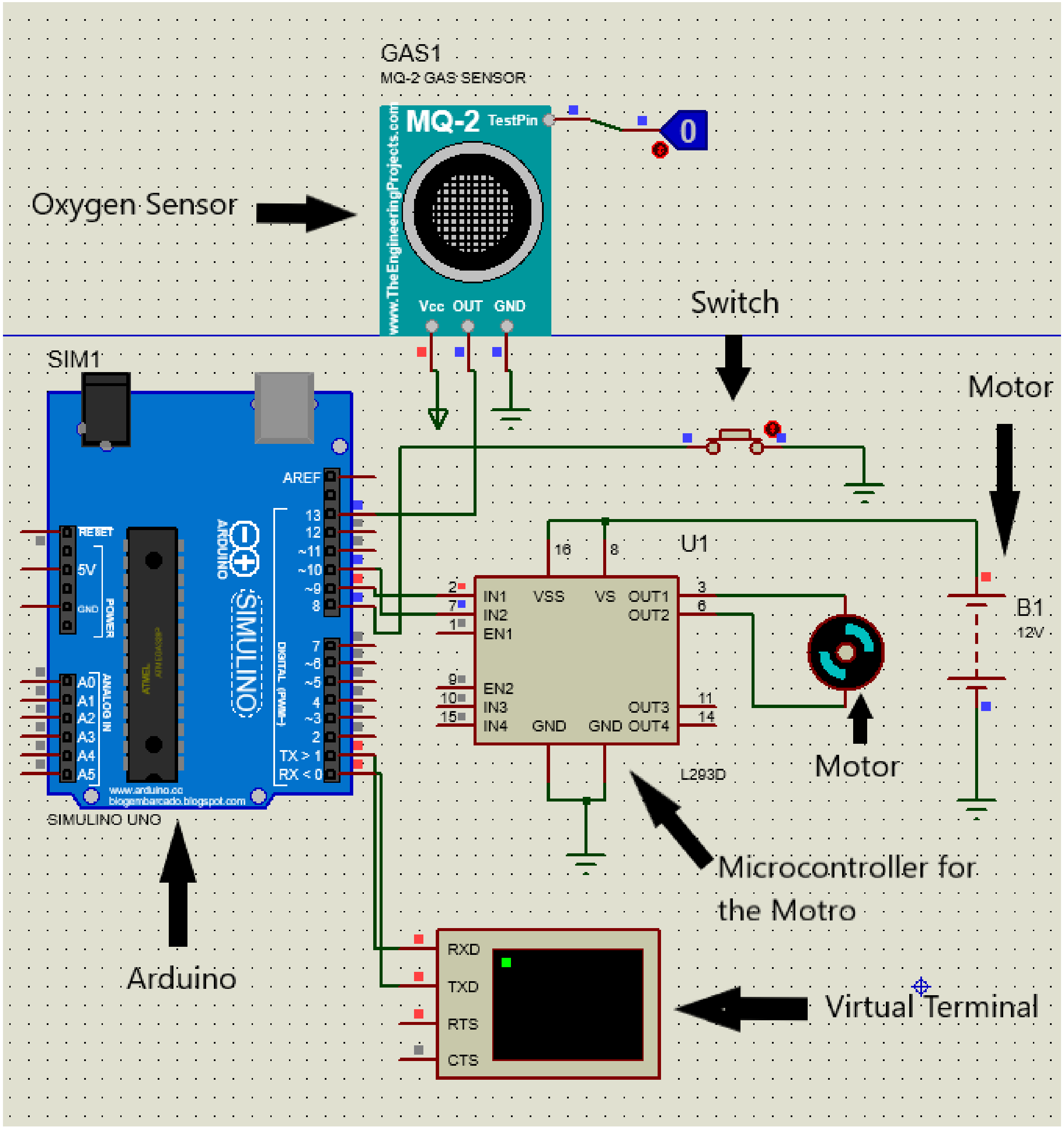
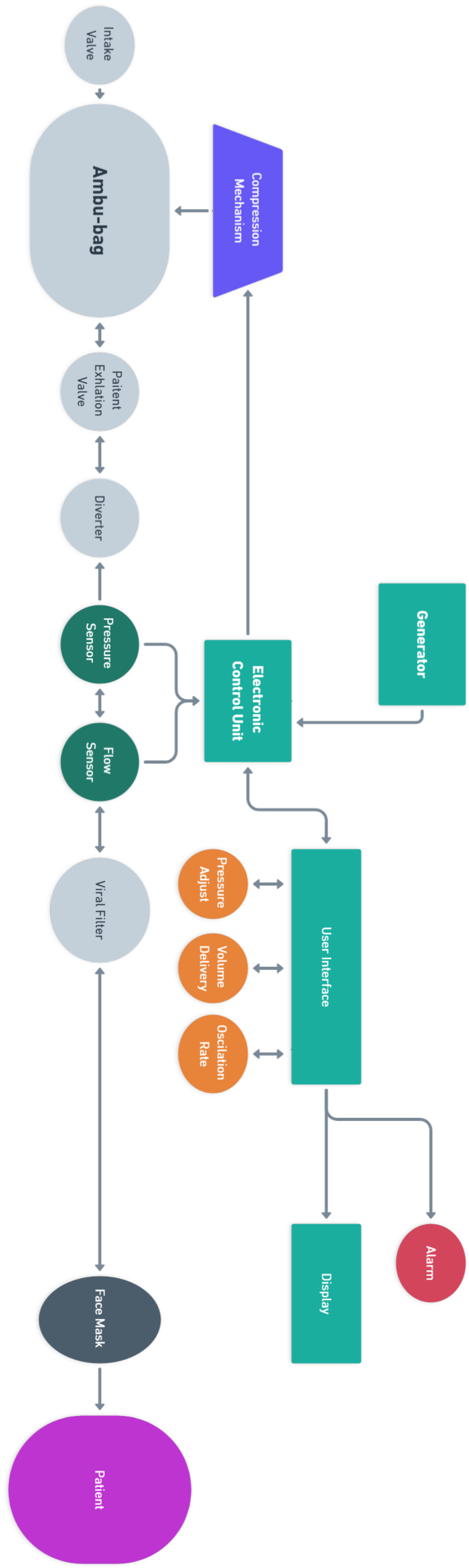


Figure 2.7: Arduino Circuitry

Figure 2.8: Block Diagram



Chapter 3

Budget and resources

Equipment name	**Price**	**Company/Website**
Arduino Uno	$7.99	newegg
Ambu Bag	$29.00	Amazon
Linear Hydraulic Actuator (Qty: 2)	$70*2= $140.00	progressiveautomations
Adjustable AC to DC Power Voltage Converter	$42.89	Amazon
Adjustable Pressure Sensor	$42.89	Amazon
Spirometer (Air Flow Sensor)	$14.99	medicalsupplies
Breadboard	$5.54	digikey
LCD Display Panel	$5.00	Amazon
Trigger Buzzer Alarm Sound Module for Arduino	$9.79	Amazon
Jumper Wires M/M	$6.99	Walmart
Kodak Fillament	$33.00	medicalsupplies
Total Cost of Manufacture	$310.5	

Chapter 4

Project Components Calibration Calculations:

4.1 Design calculation

Design calculations:

- **Calculations for Z-Compression Force (F_2) to compress Ambu® Bag:**

    - For this project we are using a linear hydraulic actuator. We calculate the stress or "*force per unit area,*" given by the following formula. Plug in the value for the Pressure (P) and Area (A) to find the value of the Z-Compression Force ($\boldsymbol{F_2}$):

$$\boldsymbol{F_2} = \frac{P}{A} = \frac{2942\ Pa}{\pi\ (0.064\ m)^2} = \mathbf{38.0}\ [\boldsymbol{N}]$$

Conversions:

- **Pressure requirement**= 30 [cm $H_2 0$] = 2942 [Pa]
- **Area** = $\pi\ (r)^2$
    - Ambu® bag diameter (from data sheet) = 128 [mm]
        - Radius r = 64 [mm] or 0.064 [m]

- **Calculations for Z-Compression Force (F_1) exerted by Linear Actuator:**

  - We calculate the Z-Compression force exerted by linear actuator **(F_1)**, by using the principles of moments (torque). To achieve compactness in the design of the ventilator system, we constrained the device's total linear length (along the x-axis) to be < 0.5 m. Therefore, we choose $d_1 = 0.3048\ m\ and\ d_2 = 0.10\ m$.

$$F_1 d_1 = F_2 d_2$$

$$F_1(0.3048\ m) = (38\ N)(0.10\ m)$$

$$\boldsymbol{F_1 = 12.5\ [N]}$$

Conversions:

- **Force**= 12.5 [N] = 3 [Lbs]

- **Linear Actuator Equation:**
  - We utilized the Current-Load relationship graph (from data sheet), provided by the manufacturer in the data sheet for the component, to map the relationship between the Current (A) and the Load (lbs) of the linear actuator.

$$\boldsymbol{slope\ (m) = \frac{\Delta y}{\Delta x} = \frac{3.20 - 1.0}{20 - 0} = 0.110\ [\frac{A}{lbs}]}$$

  - Relationship between Current (A) and Load (lbs):

$$\boldsymbol{y = 0.110\ x + 1}$$

$$Where:\ y = current\ (A), \qquad x = Load\ (lbs)$$

$$y = (0.110)(3lbs) + 1$$

$$\boldsymbol{y = 1.33\ [A]}$$

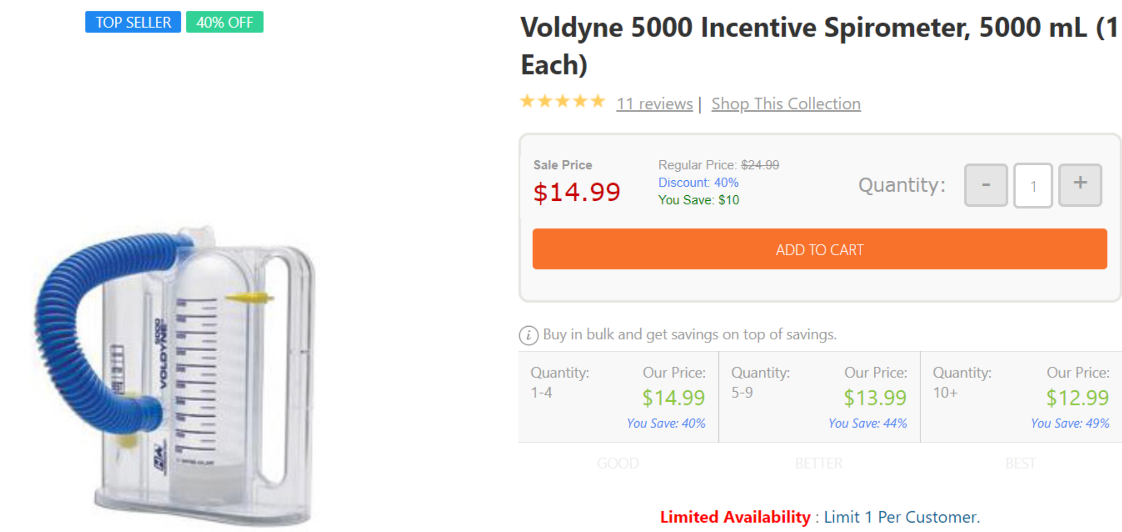
4.2 Flow Sensor (Spirometer):

Figure 4.1: Voldyne Incentive Spirometer

Product Highlights

PRODUCT FAMILY	Voldyne Incentive Spirometer
BRAND	Hudson RCI
ITEM NO.	92719009
ITEM NAME	Voldyne® 5000 Incentive Spirometer
DESCRIPTION	5000 mL
PACKAGING	1 Each
MANUFACTURER	Teleflex, Inc.
MANUFACTURER PART NUMBER	8884719009

Figure 4.2: Voldyne Incentive Spirometer



4.3 Actuator

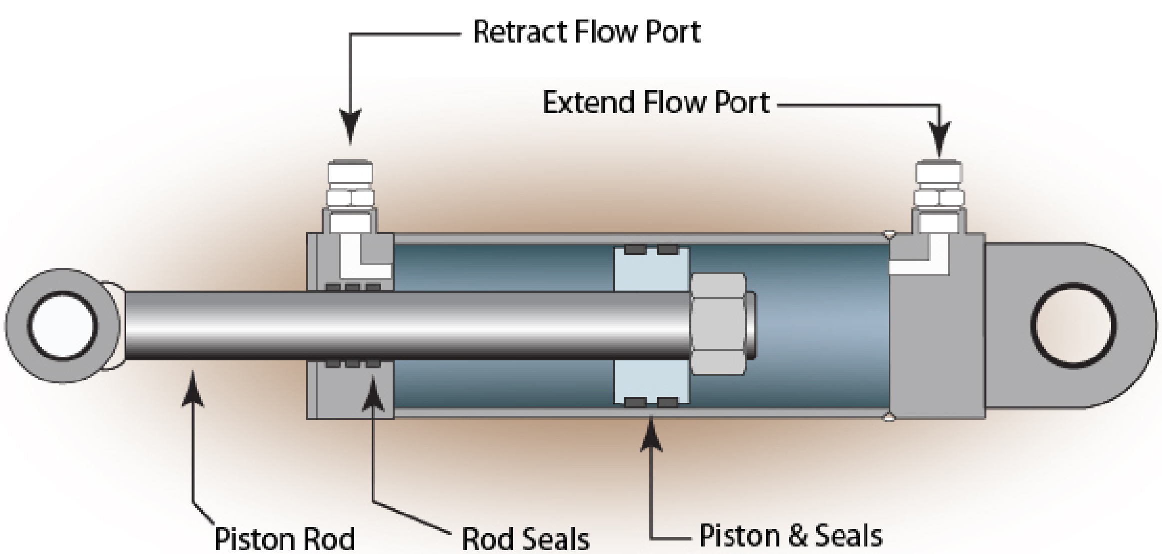
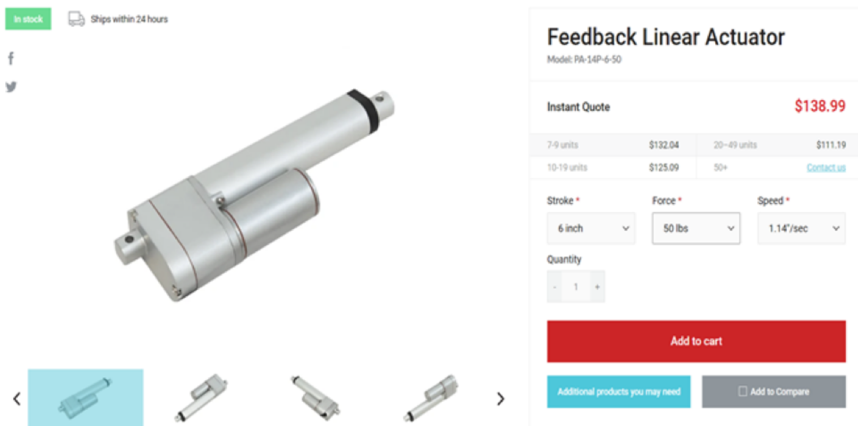


Figure 4.3: Mechanism of an actuator

4.3.1 Pneumatic components Specification

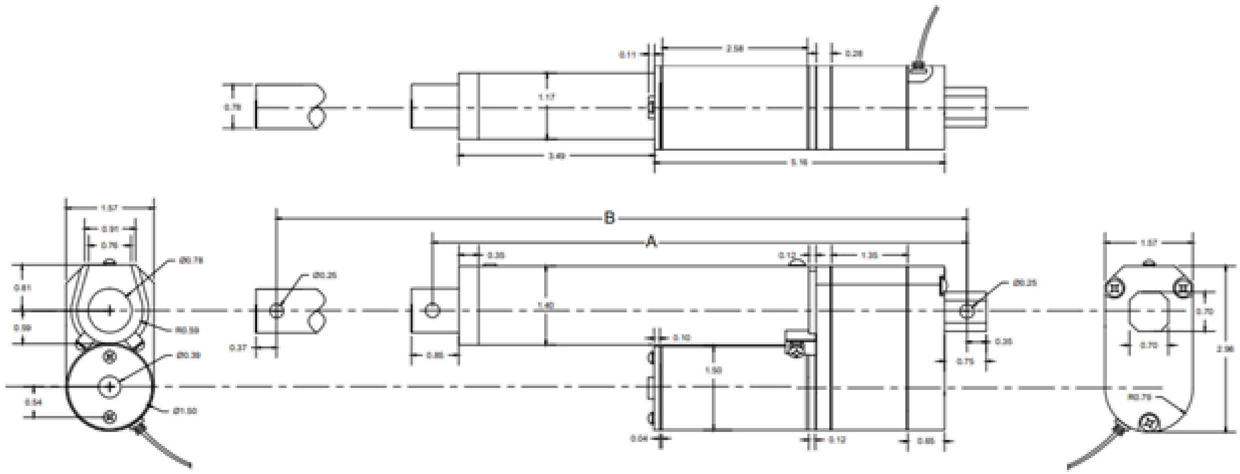


4.3.2 Specifications:

Load (LBS)		No Load Current (A)				Full Load Current (A)				Speed (inch/sec)	
Dynamic	Static	12VDC	24VDC	36VDC	48VDC	12VDC	24VDC	36VDC	48VDC	No Load	Full Load
35	75	1.0	0.5	0.3	0.3	5.0	2.5	1.7	1.3	2.00	1.38
50	100	1.0	0.5	0.3	0.3	5.0	2.5	1.7	1.3	1.14	0.83
75	150	1.0	0.5	0.3	0.3	5.0	2.5	1.7	1.3	0.95	0.70
110	220	1.0	0.5	0.3	0.3	5.0	2.5	1.7	1.3	0.79	0.59
150	300	1.0	0.5	0.3	0.3	5.0	2.5	1.7	1.3	0.37	0.28

Stroke	1" to 40"
Limit Switch	Internal - Non-Adjustable
Limit Switch Feedback	Customizable
Screw Type	ACME Screw
Motor Type	Brushed or Brushless DC Motor
Connector Type	See Page 5
Wire Length	40" (customizable)
Housing Material	6062 Aluminum Alloy
Rod Material	Aluminum Alloy/Stainless Steel (customizable)
Gear Material	Polyformaldehyde (35 lbs only)/Powder Metallurgy Steel Alloy
Color (Shaft)	Silver
Color (Motor End)	Silver
Noise	<45dB
Duty Cycle	25% (5 minutes on, 15 minutes off)
Operational Temperature	-25ºC to 65ºC (-13ºF to 149ºF)
Protection Class	IP54 (IP65 customizable)
Feedback Options	Potentiometer (see page 5)
Certifications	CE/RoHS
Mounting Brackets	See Page 6
Mounting Ends	Customizable

4.3.3 Actuator Dimensions:



Hole to Hole

	Stroke	1	2	3	4	6	8	9	10	12	14	16	18	20	22	24	30	40
PA-14P	A	6.51	7.51	8.51	9.51	11.51	13.51	14.51	15.51	17.51	19.51	21.51	23.51	25.51	27.51	29.51	35.51	45.51
	B	7.51	9.51	11.51	13.51	17.51	21.51	23.51	25.51	29.51	33.51	37.51	41.51	45.51	49.51	53.51	66.61	85.51

For Stroke Length

A = Stroke Length + 5.51"

B = Stroke Length x 2 + 5.51"

Figure 4.4: Dimensions of an actuator

4.3.4 Actuator Speed Vs Load Graph:

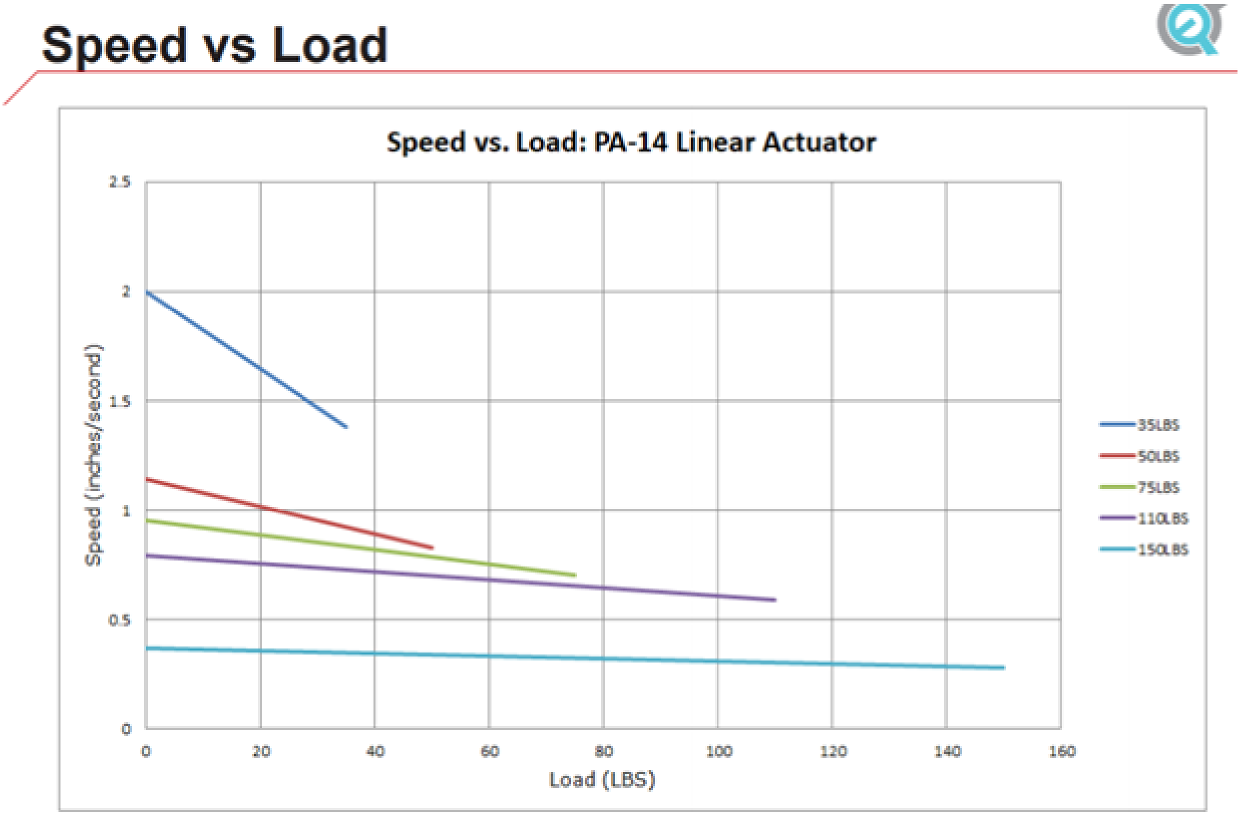


Figure 4.5: Actuator Speed Vs Load Graph

4.3.5 Actuator Current Vs Load Graph:

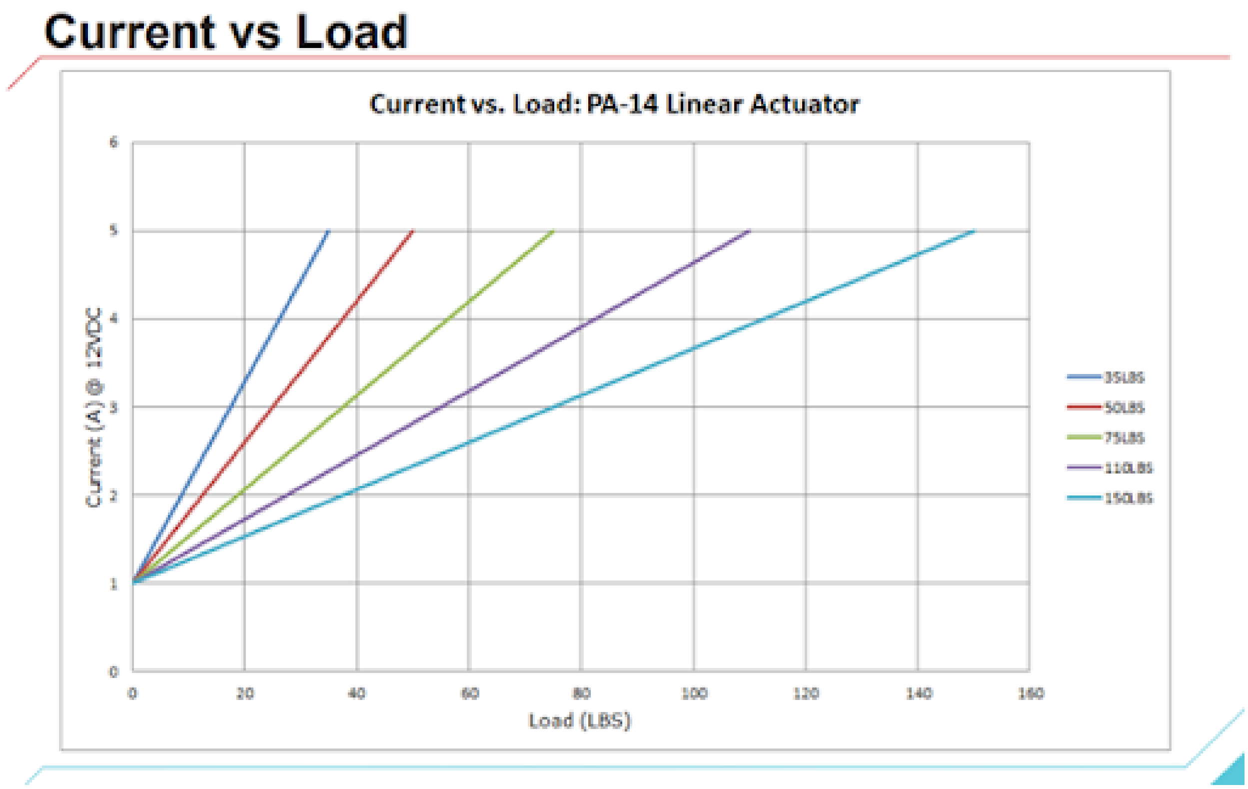


Figure 4.6: Actuator Current Vs Load Graph

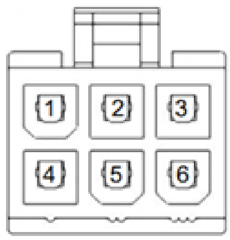
4.3.6 Actuator Specifications Settings:

Actuator Specifications and Settings	
Current (A)	1.33 [A]
Voltage (V)	12 [V]
Stroke	6 [Inches]
Speed of Compression	180 [Inches/min] or 3 [Inches/sec]
Force of Compression	3 [lbs] or 12.5 [N]
Duty Cycle	50% (Custom Manufacture)
Actuator Model	PA-14P-6-35
Feedback Mechanism	Potentiometer
Price (Per Piece)	**Original Price = $140,** **Negotiated Price= $70 (-50% Discount)**

4.4 Potentiometer Feedback Specifications:

Potentiometer Specifications

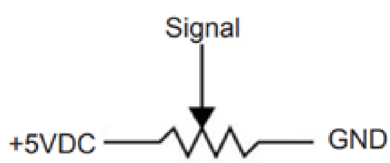
*For Stroke Length up to 40"



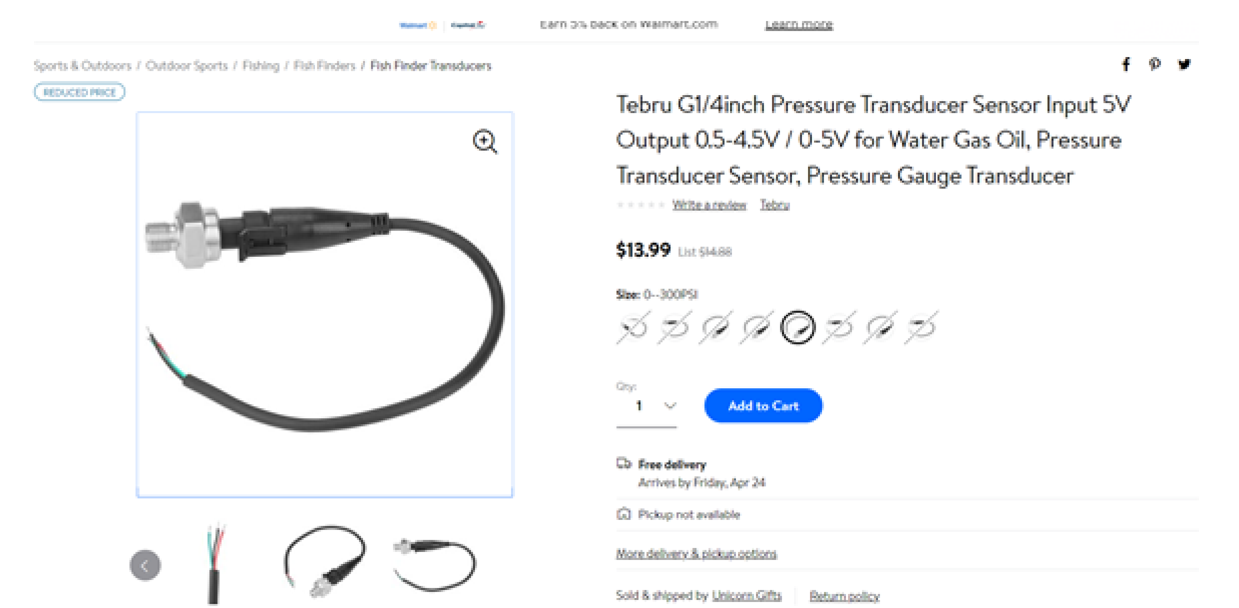
Motor		Potentiometer			
4	5	2	3	1	6
-	GND (White wire)	Actuator Negative (Red Wire)	Potentiometer (Blue Wire)	Actuator Positive (Black Wire)	5V (Yellow Wire)

Resistance*	Number of Turns	Tolerance
0-10kΩ	10	+/- 5%

*Actual resistance value may vary within the 0-10kΩ range based on stroke length

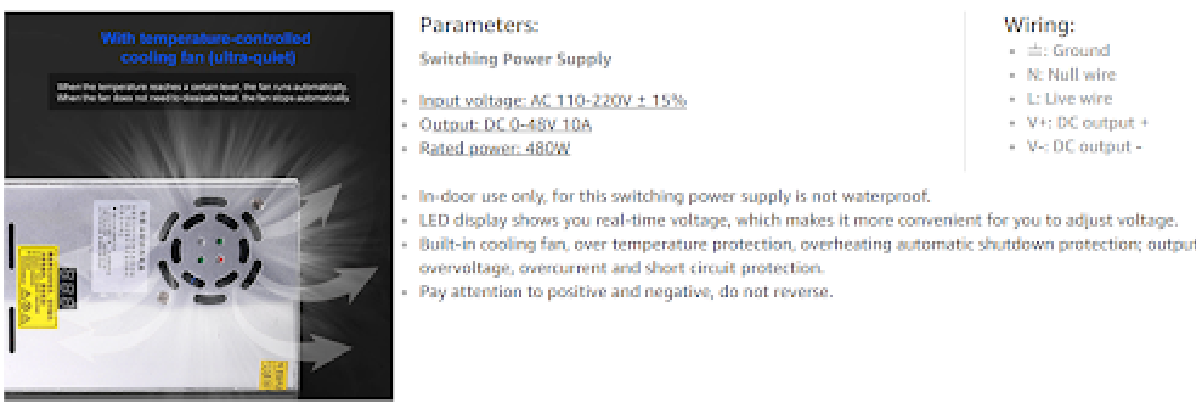


4.4.1 Pressure Sensor:



4.5 AC to DC converter:

Figure 4.7: AC to DC converter



Note:

Switching Converter

Before using, please select the input voltage 110V/220V according to your local voltage, to avoid damaging, switch is at right side of the item.

If use motor, fan and other inductive load, please pay attention to the load's maximum starting current parameter. This parameter shall not be higher than the power supply's max. current.

Otherwise it may damage the power supply. Or allocate the soft starting protection circuit for the load to absorb the impact current.

Package includes:

- 1 x Switching Power Supply

4.6 Ambu Bag:

Specifications

Description	Adult	Paediatric	Neonate
Stroke volumes	700 ml	450 ml	150 ml
Patients weight	> 30 kg (10 years)	10-30 kg (1-10 years)	< 10 kg (1 year)
Total bag volume	1475 ml	635 ml	220 ml
Dimensions (length x diameter)	291 mm x 128 mm (11.45 in. x 5 in.)	245 mm x 99 mm (9.65 in. x 3.9 in.)	165 mm x 70 mm (6.49 in. x 2.7 in.)
Oxygen reservoir volume	1500 ml	1500 ml	1500 ml
Patient connector Outside	22 mm (ISO)		
Patient connector Inside	15 mm (ISO)		
Expiratory connector (for PEEP valve attachment)	30 mm male (ISO)		
Forward and backward leak	Not measurable		
Operating temperature	-18° C to 50°C (-4° F to 122° F) at humidity between 15% and 95%		
Storage temperature	-40° C to 60° C (-40° F to 140° F) at humidity between 40% and 95%		

Ambu Oval Plus Silicone Resuscitators can be autoclaved repeatedly at 134°C
This product does not contain natural rubber latex.
The bags are made of silicone rubber

Chapter 5

Other Designs

5.1 MIT design

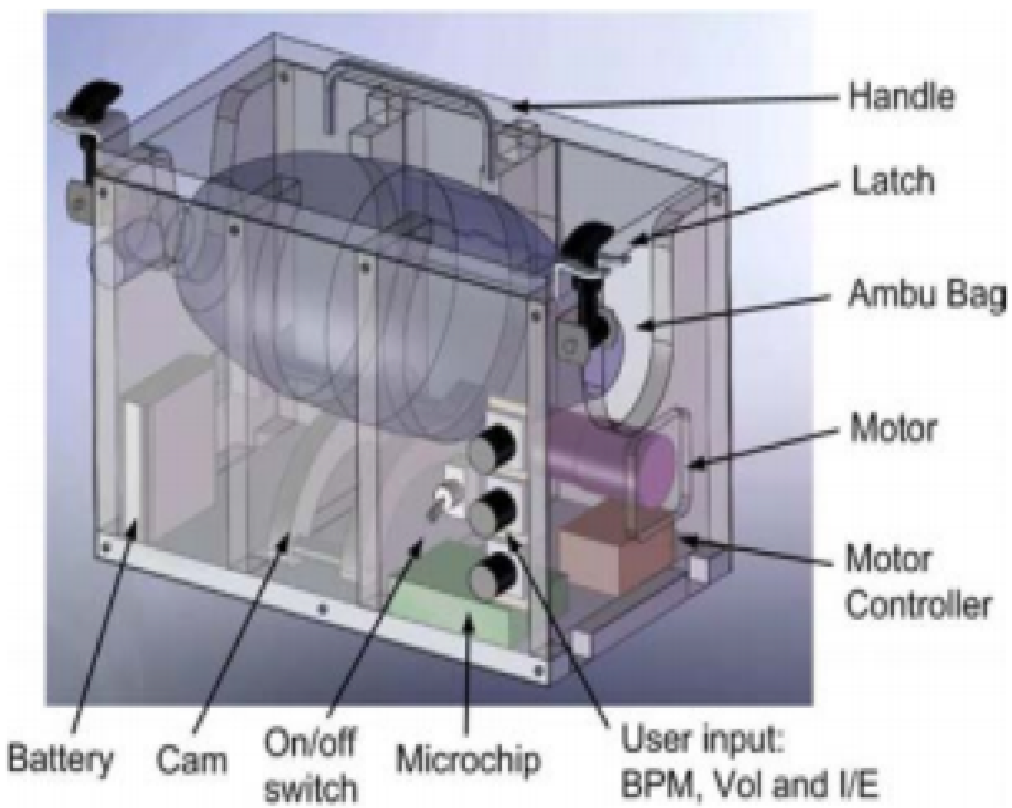


Figure 5.1: MIT prototype

This design was fabricated by MIT students. It is a design and prototyping of a low-cost portable mechanical ventilator for use in mass casualty cases and resource-poor environments. The ventilator delivers breaths by compressing a conventional bag-valve mask (BVM) with a pivoting cam arm, eliminating the need for a human operator for the BVM.

MIT students are partaking in this challenge to design a low cost ventilator that can impact patients during this pandemic [Al +10].

5.2 Rice University design

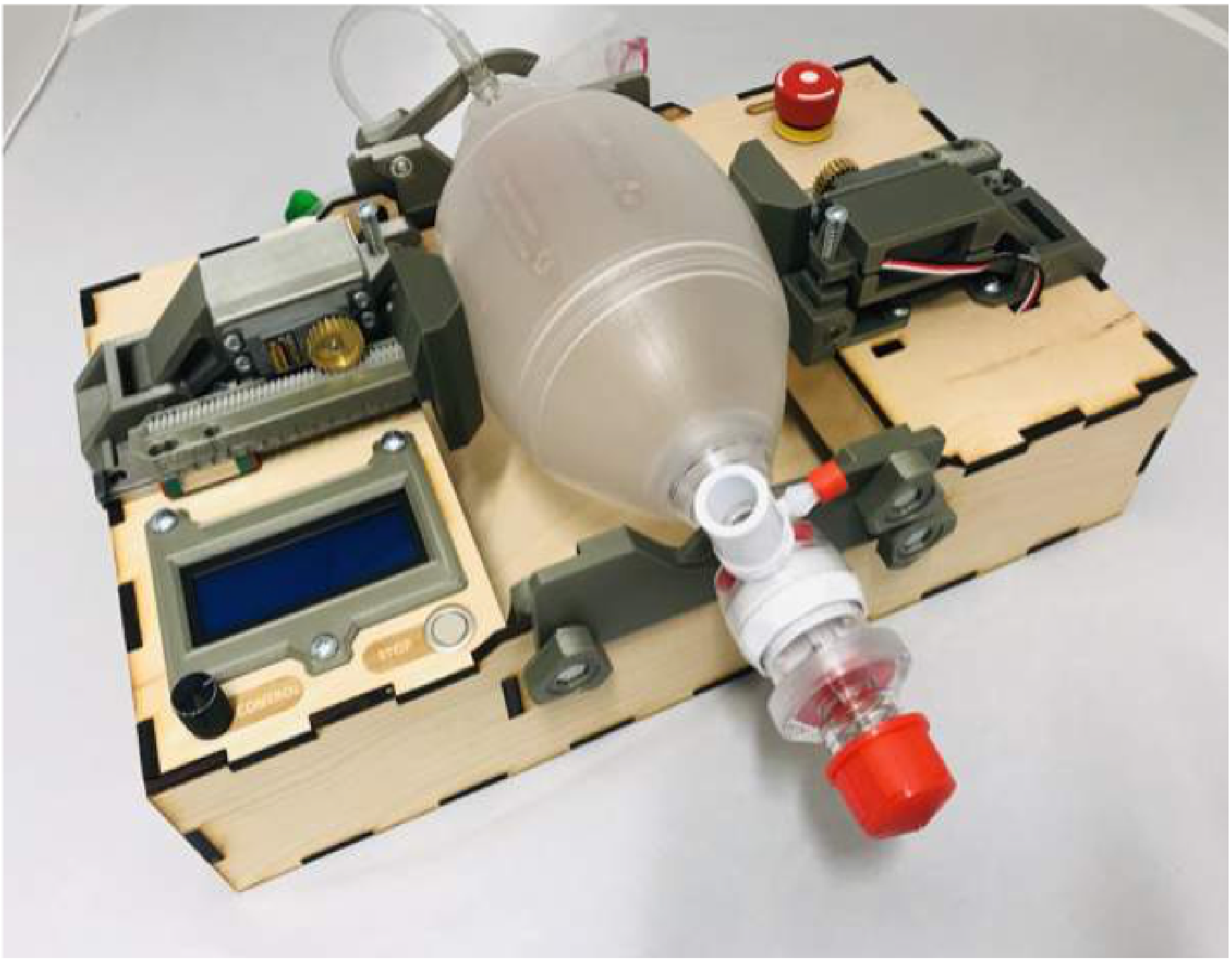


Figure 5.2: MIT prototype

Rice University students designed this device that will provide comfort to Covid19 patients as they wait for a ventilator to become available. Students named the device, Apollo BVM, and those interested in designing the mask can access the device's website on how-to-instructions. In March of 2019, a group of Rice University senior students designed ApolloBVM, and brought the device up to medical grade through the help of Rice engineers and Texas Medical Center doctors. The device was part of a project and works by squeezing a common bag valve mask nonstop and costs less than $300 in parts.

Chapter 6

Limitations and failure modes

6.1 Failure Modes (Hardware)

[PC89]

- **Generator**: Generator converts mechanical energy into electrical energy and is responsible for ventilator power supply. Generators can fail in power surges. Power surge leaves you with no power when you need it. This can make your system vulnerable if you are not able to fix it.
- While the motor is working, the rotating wheels will touch the right side of the lever consequently providing a force.
- **Fix/Prevention:** To prevent power surge, you have to use surge protector. Surge protector protects electrical appliances from voltage spike. A voltage spike is a sudden increase in voltage that lasts for less than 3 nanoseconds.Generator has a gradual degradation. It will happen over time. The generator output power (in watt) for certain loads will degrade or go down and regular maintenance can prevent it. Other causes of generator failure are battery failure, fuel leak, oil leak, etc.
- **Pressure Sensor:** Pressure sensor is used to measure pressure applied to the patient (inhalation) and in some ventilators, it measures pressure of the gases leading to an external humidifier. Pressure sensors might come with factory defects: If the pressure sensor has factory defects that need to be tested after purchase or manufacturing, it can be replaced under the warranty period.
- **Overload:** Another conflict we might have with pressure sensors is overload. First, we need to understand the rating of the sensor. If the pressure rating is 10 pascal then you cannot apply more pressure.
- **Pressure sensor mechanical failure:** it can have sudden mechanical failure, ideally replacement is the fix.
- **Pressure electrical failure:** If the electrical wire from the pressure sensor fails, you have to maintain and inspect the wires and replace them if they are damaged.
- **Alarm:** Alarm in a ventilator is responsible for indicating pressure. It indicates whether the pressure is low pressure or high pressure. Electrical failure can happen in alarms. Replace if alarm is not functional. Additional problems with alarms can be

water in the ventilator circuit, increased or thicker mucus blocking the airway. This might be caused by lack of humidity.

- **Microcontroller:** It is responsible for providing the selective venting of expiration gases, and the selective mixing of treatment gases, such as anesthesia. Electronic devices are reliable. However, it can still fail. It needs to have electrical surge protection called ESD. ESD surge protectors are used for protecting electronic circuits in consumer devices. Therefore, ESD surge protectors can be used to prevent failure in microcontrollers.

- **Valve:** [Spa11] Valve is a key element of any ventilation system. Tasks of the valve include controlling the respiratory phases. Their design prevents internal ventilator components from coming into contact with the patient's exhaled gas. Failures in valves can be caused by many factors such as Temperatures or pressures outside the designed operating parameters, incorrect assembly, installation, or maintenance procedures performed on valve, water or foreign object in in plant airline, etc.

- **Fix/Prevention:**
  - Identify location of valve failure (seat, body, actuator, etc.)
  - Take necessary troubleshooting steps to further identify root cause or to resolve while the valve is in place.
  - Ensure appropriate spare parts are on hand before removing the valve from service.
  - Remove valve from piping (if necessary) following appropriate procedures, including air and electrical disconnection.
  - Follow proper disassembly and maintenance procedures to resolve issues and reassemble valves.
  - Re-install valve into piping with correct air and electrical connections.

These are some hardware parts that can fail in a ventilator and this will cause the ventilator to malfunction.

Below are some additional causes that can make a ventilator malfunction.

1. Ventilator Problems: Inappropriate settings, high airway pressure alarm limit too low, excessive flow or excessively short inspiratory time.

2. Circuit Problems: Fluid pooling in circuit, fluid pooling in filter, etc.

3. Decreased respiratory system compliance: Decreased ventilated lung volume, decreased chest wall compliance due to patient fighting ventilator, etc.

- Some ways to prevent these conflicts are and Assess patients:

- Disconnect the patient from the ventilator and manually ventilate and assess the lungs. Check to see if the patient is difficult to ventilate. If the patient is not difficult to ventilate then the problem is with the ventilator or the circuit. If the patient is difficult to ventilate it is a problem with the respiratory system.

- For ventilator and circuit problems check ventilator settings and function, and check circuit for obstruction

- If the cause is still not clear measure inspiratory pause pressure. If airway pressure is high then the problem is due to poor compliance.

6.2 Team members and roles:

Member	Roles
Elis Cucka	• TinkerCad 3D-Model Design of the Ventilator • Exploration and research to different ventilator designs • Circuit Simulation in Proteus Software • Circuit Experiment Report • Ventilator Designs Timeline • Conducted research on respiratory diseases and the requirements need for our ventilator
Hashir Saifullah Syed	• Responsible for synthesizing the blueprint idea for the ventilator design and implementing in TinkerCAD 3D-model. • Responsible for designing the block diagram for the system and calibrating the ventilator system by calculating values of the Z-Compression force, pressure, and related parameters. • Conducted literature review of engineering research related to DIY ventilator designs. • Conducted research on project components and specifications, in line with the design requirements. Negotiated price for the components.
Inzamam	• Research hardware failure modes • Conducted literature review • Research project design and specifications • Research additional models of ventilators
Hamad El Kahza	• Assist with the 3d Designs • Research the need of ventilators • Collaborate with team members to create the projet report using Latex • Simulating the design using Qt creator and Arduino Software

6.3 Weekly Progress:

Project Timeline

Team Members	Week# 1	Week# 2	Week# 3	Week# 4	Week# 5	Week# 6
Elis	Literature Review	Literature Review	Prototype Designing	Prototype Designing	Prototype Design Analysis	Project Finalization
Hashir	Literature Review	Literature Review	Prototype Designing	Prototype Designing	Research on Project Component Specifications	Project Finalization
Inzamam	Literature Review	Literature Review	Research on additional design	Hardware failure modes	Report Write up	Project Finalization
Hamad	Literature Review	Literature Review	Software Simulation	Arduino Code	Report Conversion in Latex	Project Finalization

Figure 6.1: Weekly Progress

Appendix A

Software

```

// Setting analog value to 0
int val = 0;

//Pin 13
int pir = 13;


void setup()
{
  //Virtual Terminal starting function
  Serial.begin(9600);
}

void loop()
{
  //Reading input from Pin 13
  int pir_input = digitalRead(pir);
  //Reading input from Pin 10
  int button = digitalRead(8);
  //Reading input from Pin 11
  int button2 = digitalRead(12);

  //If Switch is ON
  if(button == LOW)
  {
      //Setting value to 100 (it can be 0 - 255)
      val = 50;
      Serial.println("Analog␣Value␣is␣100.");
      //Pin 9 Analog Writing
      analogWrite(9,val);
      //Pin 10 Analog Writing
      analogWrite(10,0);
      //Delaying half of a second
      delay(500);
  }
```

```
  //If sensor does not detect oxygen
  if(button2 = LOW)
  {
     //Setting value to 255
     val = 255;
     Serial.println("Analog␣Value␣is␣255.");
     //Pin 9 Analog Writing
     analogWrite(9,val);
     //Pin 10 Analog Writing
     analogWrite(10,0);
     //Delaying half of a second
     delay(500);
  }

}

/*
// Setting analog value to 0
int val = 0;

//Pin 13
int pir = 13;


void setup()
{
  //Virtual Terminal starting function
  Serial.begin(9600);
}

void loop()
{
  //Reading input from Pin 13
  int pir_input = digitalRead(pir);
  //Reading input from Pin 10
  int button = digitalRead(8);

  //If Switch is ON
  if(button == LOW)
  {
    //If sensor does detect oxygen
    if(pir_input == HIGH)
    {
      //Setting value to 100 (it can be 0 - 255)
      val = 100;
      Serial.println("Analog Value is 100.");
      //Pin 9 Analog Writing
      analogWrite(9,val);
      //Pin 10 Analog Writing
```

```
      analogWrite(10,0);
      //Delaying half of a second
      delay(500);
    }
    //If sensor does not detect oxygen
    else
    {
      //Setting value to 255
      val = 255;
      Serial.println("Analog Value is 255.");
      //Pin 9 Analog Writing
      analogWrite(9,val);
       //Pin 10 Analog Writing
      analogWrite(10,0);
      //Delaying half of a second
      delay(500);
    }
  }
  //If switch is off
  else
  {
    val = 0;
    //Displaying analog value
    Serial.println("Analog Value is 0.");
    //Pin 9 Analog Writing
    analogWrite(9,val);
    //Pin 10 Analog Writing
    analogWrite(10,0);
    //Delaying half of a second
    delay(500);
  }
}
*/
```

Bibliography

[Uni20] Columbia University Staff. *Columbia DIY Ventilator Challenge.* 10 Apr. 2020. URL: https://engineering.columbia.edu/diy-ventilator-challenge.

[PC89] SJt Pryn and MM Crosse. "Ventilator disconnection alarm failures: the role of ventilator and breathing system accessories". In: *Anaesthesia* 44.12 (1989), pp. 978–981.

[Al +10] Abdul Mohsen Al Husseini et al. "Design and prototyping of a low-cost portable mechanical ventilator". In: *Transactions of the ASME-W-Journal of Medical Devices* 4.2 (2010), p. 027514.

[Spa11] Doug Sparks. *QA: Why do valves fail?* 2011. URL: https://www.flowcontrolnetwork.com/valves-actuators/article/15555201/qa-why-do-valves-fail.

[RGJ20] Megan L Ranney, Valerie Griffeth, and Ashish K Jha. "Critical supply shortages—the need for ventilators and personal protective equipment during the Covid-19 pandemic". In: *New England Journal of Medicine* (2020).