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### DESIGN, MODELING, AND FABRICATION OF A VENTILATOR PROTOTYPE - A SUCCESSFUL STUDENT PROJECT STORY

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#### ABSTRACT

*In this work, we use a group project approach for a group of undergraduate students to design and develop a mechanical ventilator, in response to the COVID-19 pandemic. A student group project composed of a team of undergraduate students has successfully designed and fabricated a mechanical bag valve mask (BVM) ventilator prototype. It is lightweight with a single controller is driven, capable of volume adjustment, inexpensive, open-source, and designed for ease of fabrication, installation, and operation by the average user. The ventilator prototype also consists of 3D printed components and stored bought hardware. A finite element model was developed to analyze the deformation of the bag valve mask. Finally, the ventilator system is fully tested functioning properly.*

Keywords: Student project; Design; Modeling; Ventilator

#### 1. INTRODUCTION

The Covid-19 pandemic has negatively impacted human life and education. In the initial period of the pandemic, there was a severe shortage of mechanical ventilators for the Covid patients. A mechanical ventilator is a device that assists or replaces spontaneous breathing [1,2]. On the other hand, the students' normal education has been forced to change the mode to mostly virtual instruction.

Instead of passively waiting for the situation to improve, we turned the Covid into a great opportunity for students to address this real-world challenge. With this in mind, we use a group

project approach for a group of undergraduate students to design and develop a mechanical ventilator, in response to the pandemic.

In this work, the design of the ventilator is first presented. Then the finite element model is formatted to understand the stress distribution in the ventilator. The ventilator is fully assembled and tested successfully.

#### 2. DESIGN AND FABRICATION OF VENTILATOR

##### 2.1 Bag valve mask with inflating bag

The bag valve mask (BVM) with the self-inflating bag for the ventilator is shown in Figure 1. It is a Ventlab V-Care Small Adult Resuscitator VN 5000 series. The volume of the bag is 1500 mL and its tidal volume is 1500 mL. The prototype was built to accommodate different sizes of bags for adults, children, and infants.

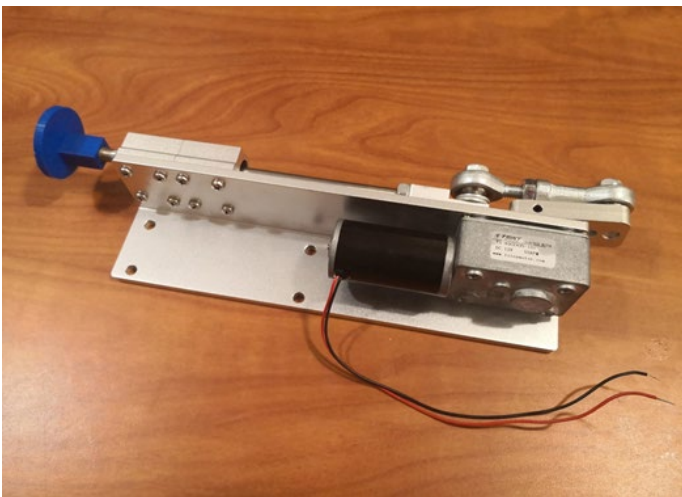


**FIGURE 1: BAG VALVE MASK WITH INFLATING BAG**

## 2.2 Linear actuator

Automating the ventilator so that continual operator intervention is not needed for safe, the desired operation, the ventilator required the following three components: A source of input energy to drive the device; a means of converting input energy into output energy in the form of pressure, and flow to regulate the timing and size of breaths; and a means of monitoring the output performance of the device and the condition of the patient.

The linear actuator reciprocating motion system (Figure 2) consists of a small 12V 5A linear actuator with a DC gear motor, a controller, and a power supply unit. The controller is used to actuate the mechanism that will push a soft pad onto the self-inflating bag. Using the reciprocating motion system, the ventilator is capable to provide an air supply with adjustable breath frequencies.



**FIGURE 2: LINEAR ACTUATOR**

## 2.3 3D printed accessories

The base frame (Figure 3) used to support the DC motor system was made of  $\frac{1}{2} \times 2 \times 4$  birch hardwood. The bag support was made of a 3D printed part with PLA plastics.



**FIGURE 3: 3D PRINTED BAG HOLDER**

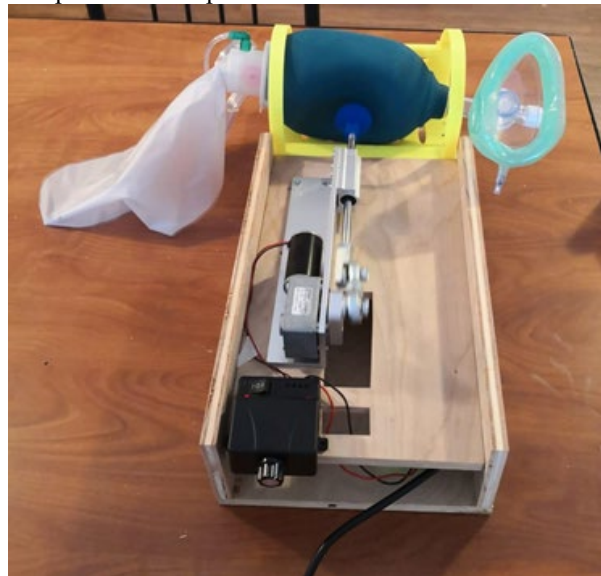
## 2.4 Finite element model of the ventilator

The objective of this finite element analysis is to conduct stress analyses on the bag of the ventilator which is made of a silicone material. Furthermore, it is important to compare the results to the real compression testing data and then perform a model exercise. Finally, to be able to conduct analysis using pressure in translational load from the motor onto the airbag. Below is the finite element mesh of the airbag.

## 3. RESULTS AND DISCUSSION

### 3.1 Assembly of the ventilator

The final assembly of the ventilator is shown in Figure 4. The ventilator is fully functional, with tunable compression patterns for specific Covid patient needs.

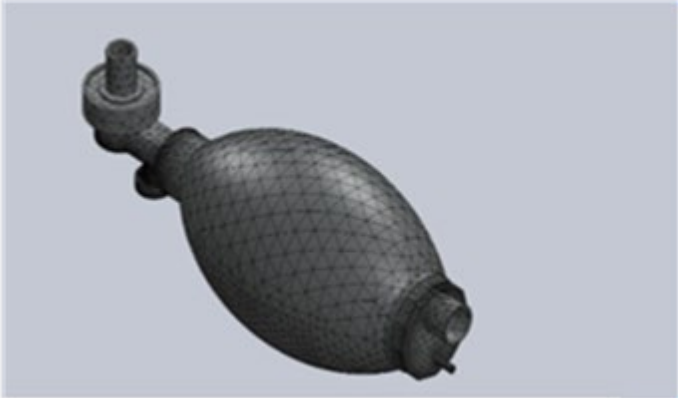


**FIGURE 4: ASSEMBLED VENTILATOR**

### 3.2 Finite element model for ventilator deformation

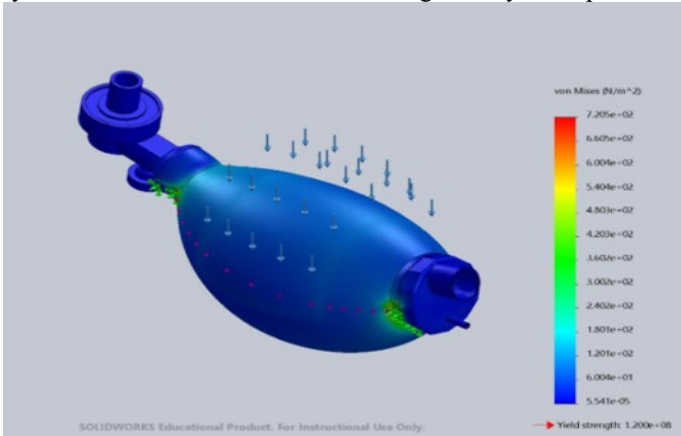
#### 3.2.1 Finite element model of the bag

Figure 5 shows the geometry and finite element mesh of the ventilator bag.



**FIGURE 5: GEOMETRY AND FINITE ELEMENT MESH OF THE BAG**

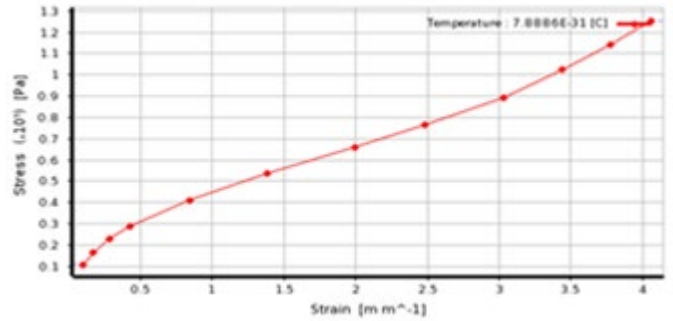
The stress distribution of the deformed ventilator bag is shown in Figure 6. It shows that the neck region of the bag has the maximum stress, suggesting a potential weak region of the system. Further reinforcement of the region may be required.



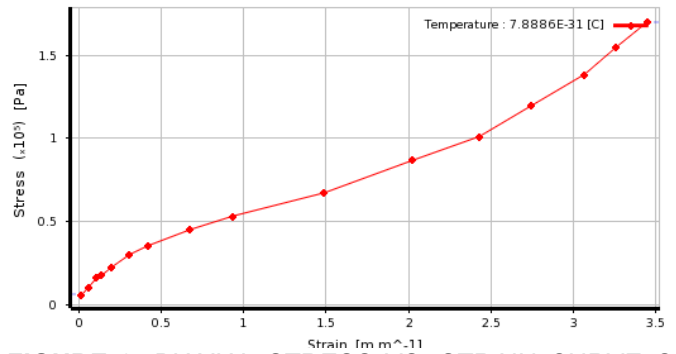
**FIGURE 6: STRESS DISTRIBUTION IN DEFORMED VENTILATOR BAG**

#### 3.3 Finite element model for silicone rubber bag materials

Since the bag material is silicone rubber, additional analysis was conducted to understand its hyperelastic properties. The stress-strain results under shear and biaxial testing conditions are given in Figure 7 and Figure 8, respectively. Both curves show that the material is highly elastic, which is suitable for airbag applications.



**FIGURE 7: SHEAR STRESS VS. STRAIN CURVE OF SILICONE RUBBER**



**FIGURE 8: BIAXIAL STRESS VS. STRAIN CURVE OF SILICONE RUBBER**

### 4. CONCLUSION

In this work, we presented a student project on the design, fabrication, and modeling of a mechanical ventilator prototype for the Covid-19 pandemic patients. The finite element model helps understand the materials and mechanical response of the ventilator. The ventilator is fully functional, demonstrating the success of the student project.

### ACKNOWLEDGEMENTS

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