EMBRY-RIDDLE Aeronautical University

Mechanical Engineering

Senior Design Poster Session

PORTABLE VENTILATOR AS AN AT-HOME RECOVERY SOLUTION

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BACKGROUND

A ventilator or "breathing machine" is a device that is used to assist breathing in patients with impaired lung function. With the onset of the COVID-19 pandemic, ventilator shortages in the United States and worldwide have become a pressing issue. Estimates of available ventilators range from 60,000-160,000 in hospital inventories, with varying levels of functionality within that group [1]. Furthermore, most ventilators available for use in hospitals are non-portable and their extended use fills hospital beds that have also faced shortages throughout the pandemic. Standard ventilators require patients to stay in the hospital for long durations, preventing doctors from sending their patients home with solutions for the long term. Between the need for beds and shortages in ventilators, beds in some hospitals reached full capacity in the height of the pandemic [1].

METHODOLOGY

Tidal volume delivery via a pump-actuated water column was posited as a solution to mechanically assist patient inspiration. The pump schematic, shown in Figure 1, displays the full flow circuit along with control elements, including unidirectional pumps and valves. Inspiratory and expiratory components of breathing are assisted by raising and lowering a water column respectively to displace a variable tidal volume at a necessary flow rate (and thus breaths per minute) according to the patient's weight and condition. For inspiratory measurement against a control reference, BioPac instrumentation is used, with a tidal volume calibration shown in Figure 2.

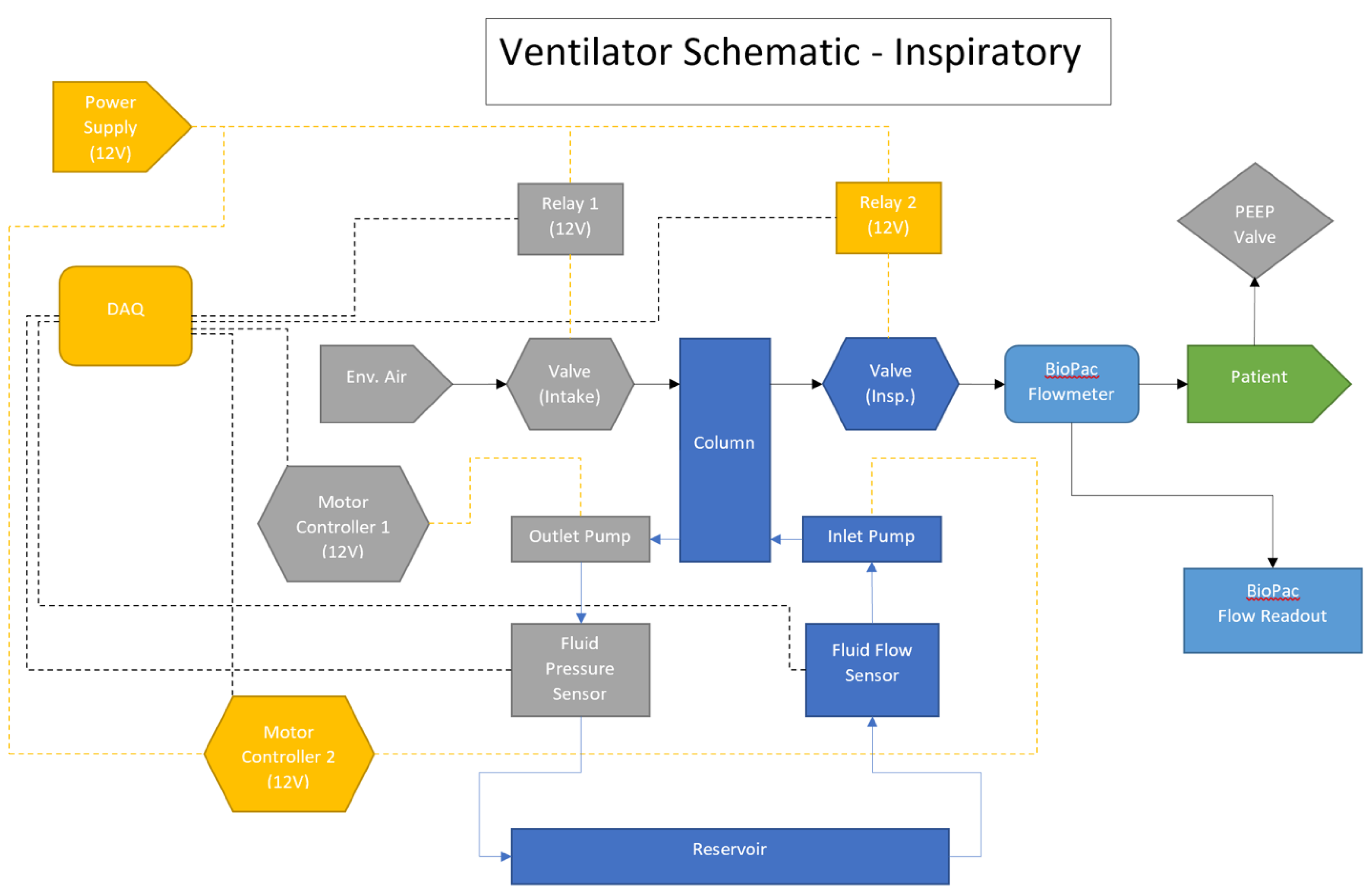

Figure 1: Ventilator schematic, showing flow diagram and control mechanisms including valves and pumps, with their respective power and logic sources.

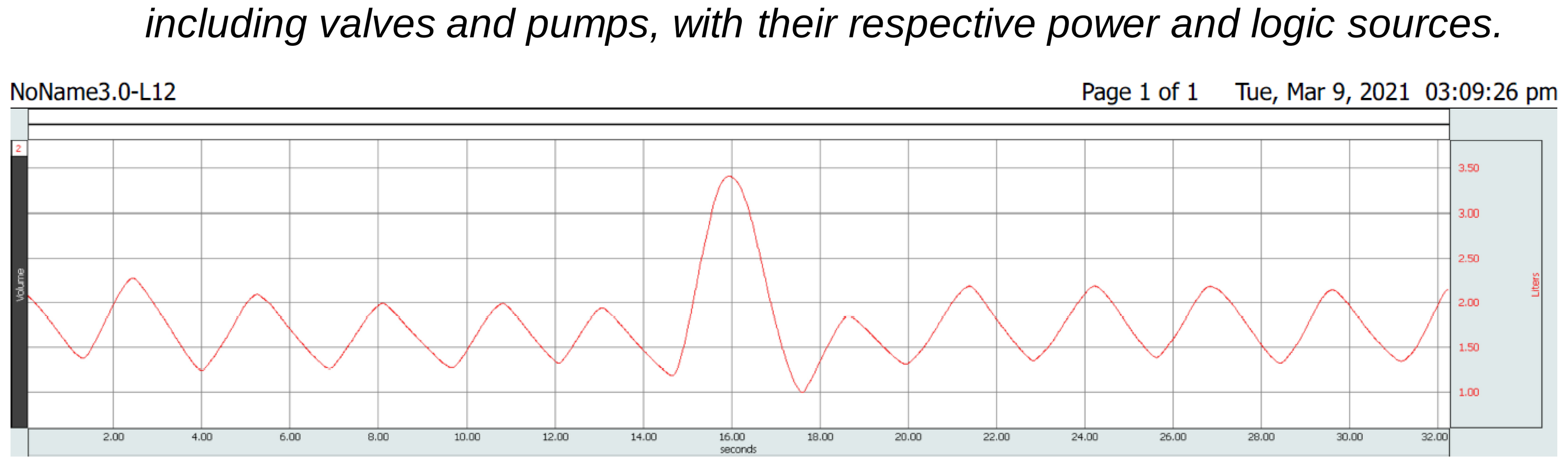

Figure 2: Biopac calibration diagram of inspiratory flow on tidal volume test.

ABSTRACT

This summary overviews the design and manufacturing a low-cost portable ventilator with remote operation capabilities for long-term continuous usage by patients with impaired lung function. This design serves as a potential solution for a lack of available ventilators and to help reduce overloading of hospital beds by acting as a bridge to patient recovery from critical condition in the hospital and at home. The ventilator is set apart from existing designs by its portability, focus on consistent operation, and remote operability by medical professionals. A hydraulic actuation system to deliver air to the patient was designed and prototyped over the preliminary phase of the project and is demonstrated through operation in inhalation and exhalation cycles. Future work includes data input from pressure and flow rate sensors to adjust flow control parameters to meet physiological requirements and a control system to modulate assisted breathing. The resulting apparatus will show feasibility of an at-home ventilator system with remote control for application to patient populations.

RESULTS

MATLAB tools were used to sweep through a variety of applicable tidal volumes and determine floor and ceiling values to define ventilator flow rate and inspiratory pressure requirements and respective water column heights. Tidal volumes, or inspiratory volumes delivered to the lungs of the patient, correspond to a relationship of 6 mL/kg [2]. An evaluation of maximum calculated inspiratory pressures for patients with required tidal volumes of 125 to 400 mL at the ceiling value of 15 BPM is shown in Figure 3 for patient weights of up to 66 kg:

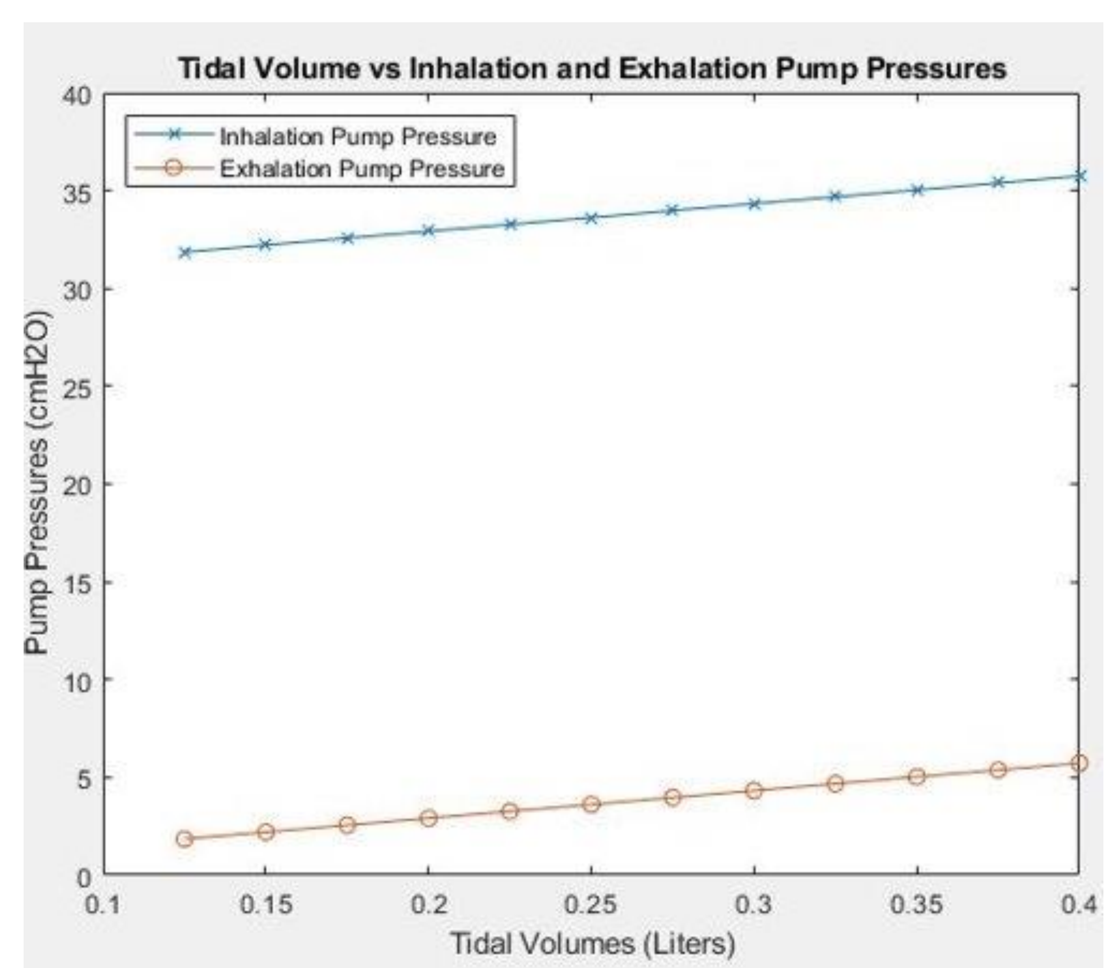

Figure 3: Patient tidal volumes and resulting pump pressures

Resulting values were used to establish duty cycle for controlling motor driver for unidirectional pumps that met flow rate and pressure requirements. Inclusion of instrumentation and a data acquisition system will help verify physiological targets have been met.

DISCUSSION

With the current proof-of-concept, demonstration of inspiratory and expiratory flows has been achieved by powering pumps in sequence. A power supply powers the motor controlled inspiratory and expiratory flow-rate pumps respectively, modelling a patient breathing at 8 BPM with a tidal volume of 350mL. Pressure and flow rate analyses led to the acquisition of new pumps to supply the flow parameters necessary to meet the full range of physiological requirements for the ventilator design. Work is underway to add valves to toggle inspiratory and expiratory states in airflow. A video demonstrating inspiratory flow is seen in Figure 4.

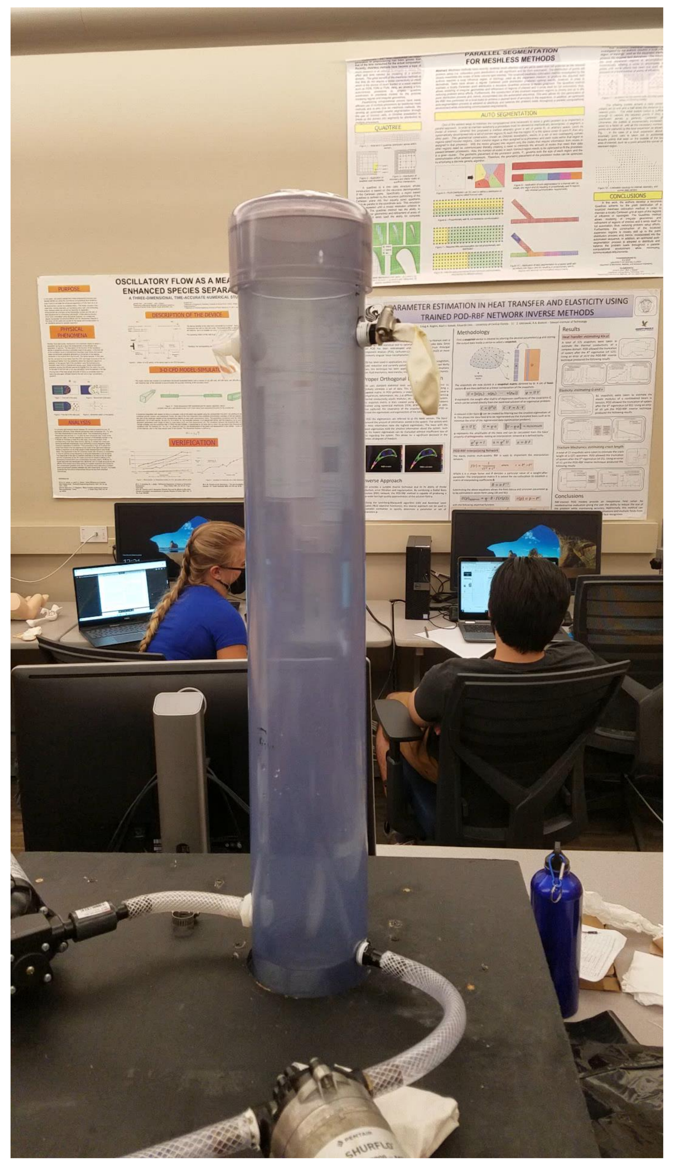

Figure 4: Inhalation simulated by pumping water in to raise the column and displace air. The air bladder inflates as the column rises.

CONCLUSIONS

The team plans to verify efficacy of the design with a data acquisition system built on the *Biopac* platform to gather data from flow rate and pressure sensors at the inspiratory output to compare against physiological requirements. Future work includes automated controls implemented in *Labview* to trigger powering of the pumps to output BPM and tidal volume controls set via a user interface. The cylinder will be truncated, and the flow loop will be optimized for a minimal profile to promote portability in the design.

REFERENCES

[1] M. Ranney, V. Griffeth and A. Jha, "Critical Supply Shortages — The Need for Ventilators and Personal Protective Equipment during the Covid-19 Pandemic", New England Journal of Medicine, vol. 382, no. 18, p. e41, 2020. Available: 10.1056/nejmp2006141.

[2] S. Goldsworthy and L. Graham, Compact clinical guide to mechanical ventilation. New York: Springer, 2014, p. 45.

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