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Assignment 1
Simulation of Respiratory Mechanics

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Submitted in partial fulfillment of the requirements for the module
BM 2102 Modelling and Analysis of Physiological Systems

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Contents

1 Introduction

This report depicts the graphs obtained from he simulator developed by David Leonardo Rodriguez Sarmiento and Daniela Acevedo Guerrero (2020), available at Simulation of Respiratory Mechanics on Simulink, MATLAB Central File Exchange, to simulate the following condition for an adult:

1. Normal
2. With a restrictive pulmonary disease
3. With an obstructive pulmonary disease,

and discusses the differences in minute ventilation.

2 Physiological Parameters Related to Respiration

- **Breathing Frequency (FR):** The number of breaths delivered per minute by the ventilator.
- **Positive End-Expiratory Pressure (PEEP):** The pressure maintained in the lungs at the end of expiration to prevent alveolar collapse.
- **Peak Pressure (PP):** The maximum pressure reached during the inspiratory phase of a mechanical breath.
- **Inspiration: Expiration Ratio (I: E):** The time ratio between inhalation and exhalation phases of a breathing cycle.
- **Respiratory Minute Volume (RMV):** The total volume of air inhaled or exhaled per minute; a product of tidal volume and breathing frequency.
- **Lung Compliance (CL):** A measure of the lung's ability to stretch and expand; lower compliance indicates stiffer lungs.
- **Chest Wall Compliance (Cw):** A measure of the flexibility of the chest wall in accommodating lung expansion.
- **Central Airway Resistance (Rc):** The resistance to airflow in the larger, central airways.
- **Peripheral Resistance (Rp):** The resistance to airflow in the smaller, distal airways of the lung.
- **Series Compliance (Cs):** Represents the combined compliance of tubing and equipment components in the ventilation system.

3 Ventilator Settings

- **Breaths Per Minute (BPM):** The ventilator delivers a set number of breaths per minute, typically 16, within the normal adult range of 12–20 BPM. This ensures adequate ventilation without overburdening the lungs.
- **Positive End-Expiratory Pressure (PEEP):** PEEP maintains pressure in the lungs at the end of expiration to prevent alveolar collapse. A typical value of 5 cm H_2O is used, supporting oxygenation and lung stability.
- **Peak Pressure:** This is the maximum pressure during inhalation, usually around 10 cm H_2O. It reflects airway resistance and lung compliance, with higher values indicating increased effort to ventilate the lungs.
- **Inspiration: Expiration Ratio (I: E):** The I: E ratio defines the time spent inhaling versus exhaling. A standard 1:2 ratio mimics natural breathing, with longer expiratory time aiding conditions like asthma by reducing air trapping.

4 Results for a Normal Adult

The reference values for a healthy adult are as follows:

- Lung compliance = 0.1 L/cm H_2O
- Thoracic compliance = 0.1 L/cm H_2O
- Airway central resistance = 3 cm H_2O/(L/s)
- Peripheral airway resistance = 0.5 cm H_2O/(L/s)
- Airway tissue compliance = 0.005 L/cm H_2O

Given below are the ventilator settings used for a normal adult

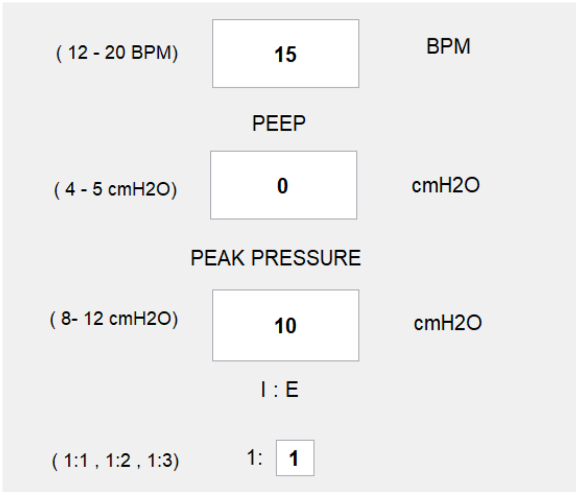

Figure 1: Values of the Ventilator

The graphs I got from the simulation are given below.

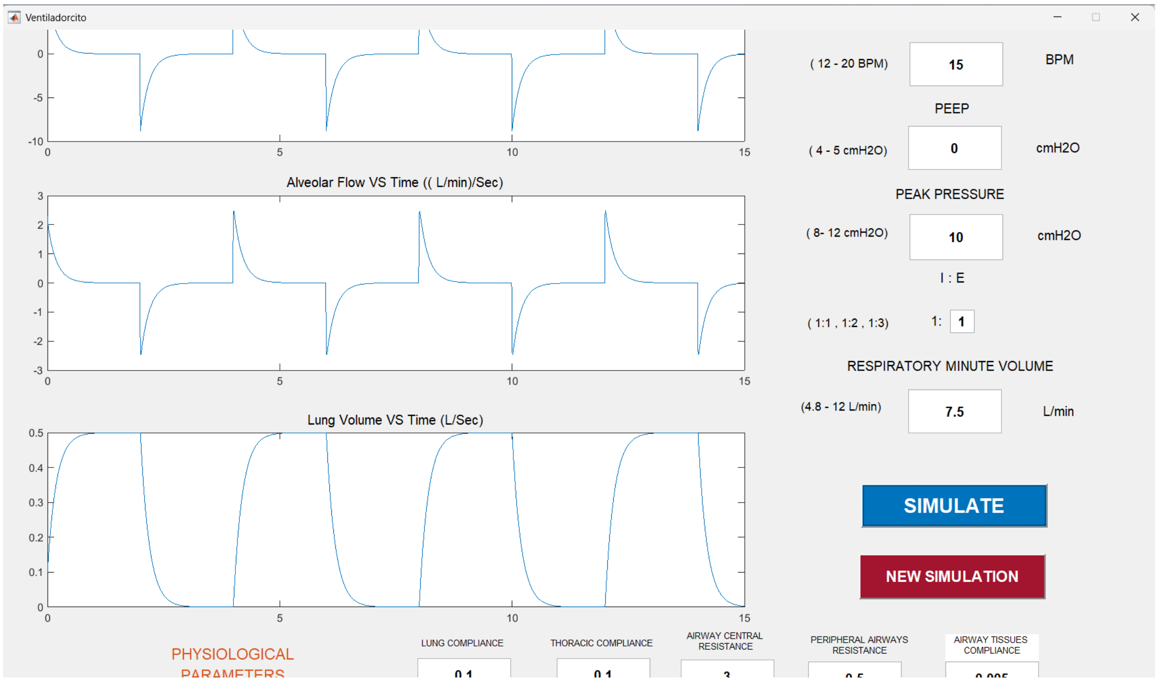

Figure 2: Simulation Results

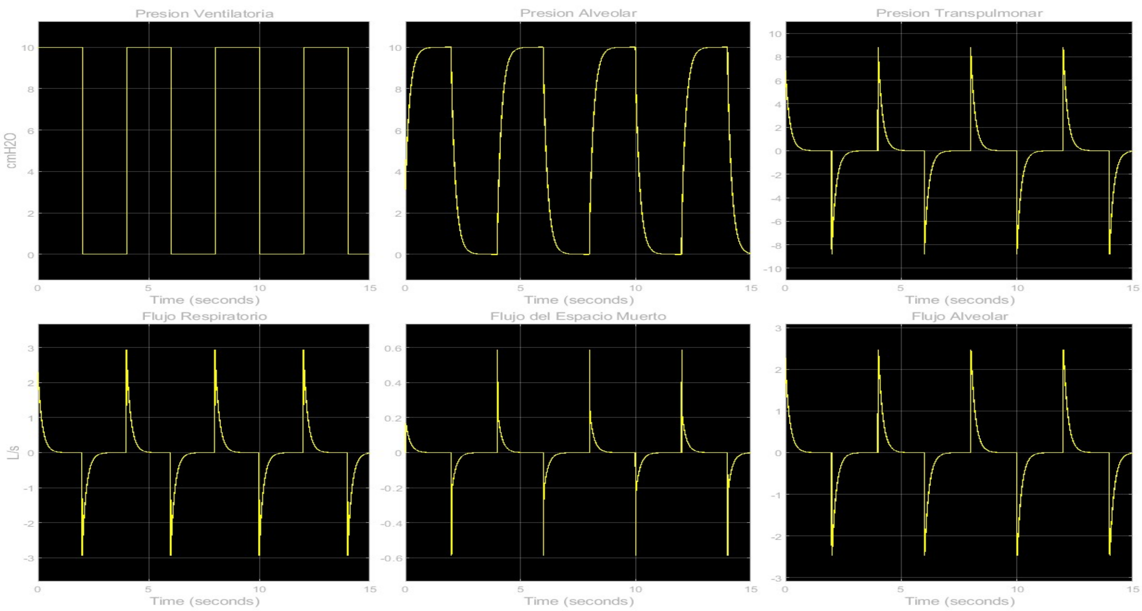

Figure 3: Simulation Results

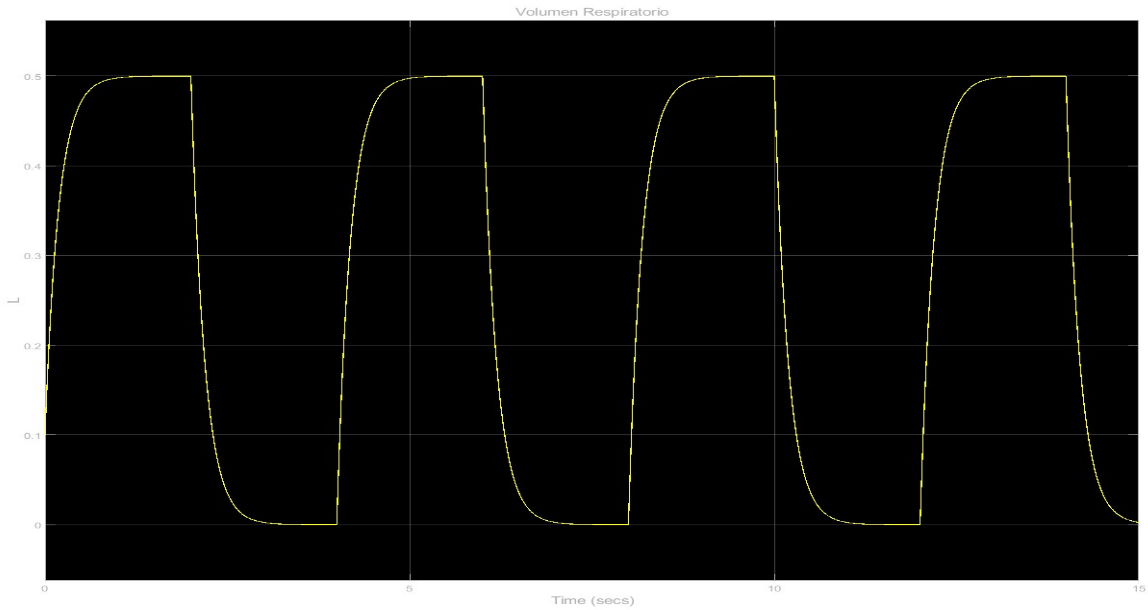

Figure 4: Simulation Results

5 Results for an Adult with a Restrictive Pulmonary Disease

In restrictive pulmonary diseases, air cannot get in because the lungs cannot expand fully due to stiffness or restriction. I have taken Pulmonary Fibrosis as the restrictive pulmonary disease of my choice.

The parameter values for an adult with Pulmonary Fibrosis are as follows:

- Lung compliance = 0.15 L/cm H_2O
- Thoracic compliance = 0.1 L/cm H_2O
- Airway central resistance = 12 cm H_2O/(L/s)
- Peripheral airway resistance = 5 cm H_2O/(L/s)
- Airway tissue compliance = 0.005 L/cm H_2O

The graphs I got from the simulation using the same ventilator parameters as above are given below.

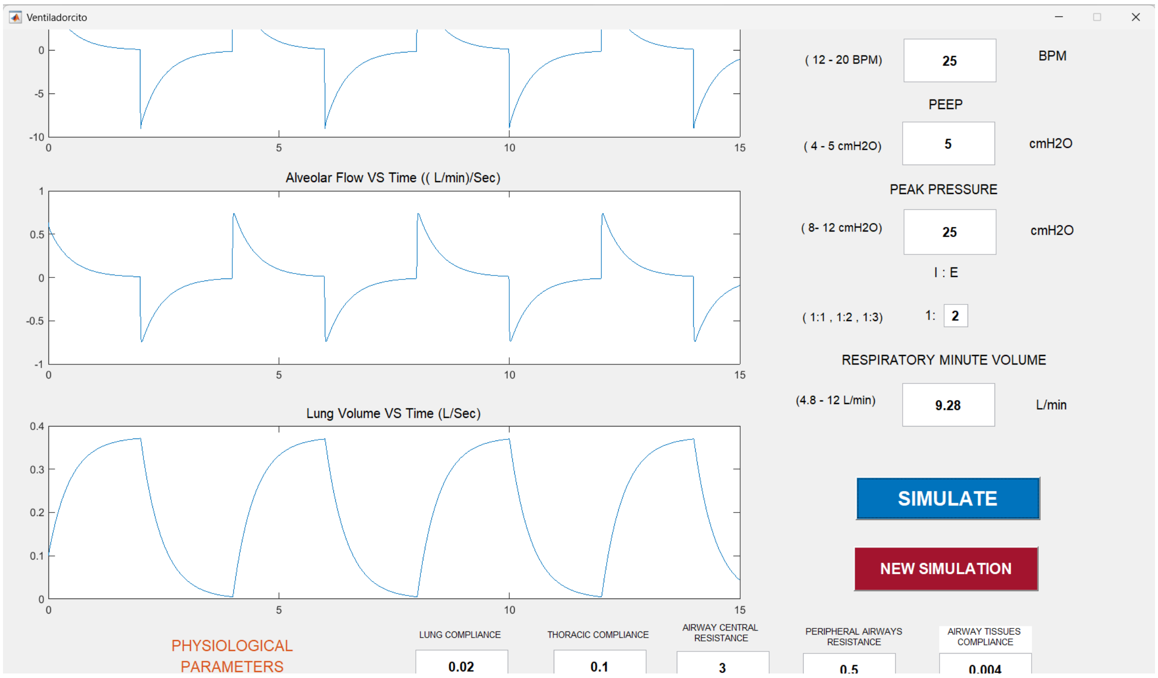

Figure 5: Simulation Results

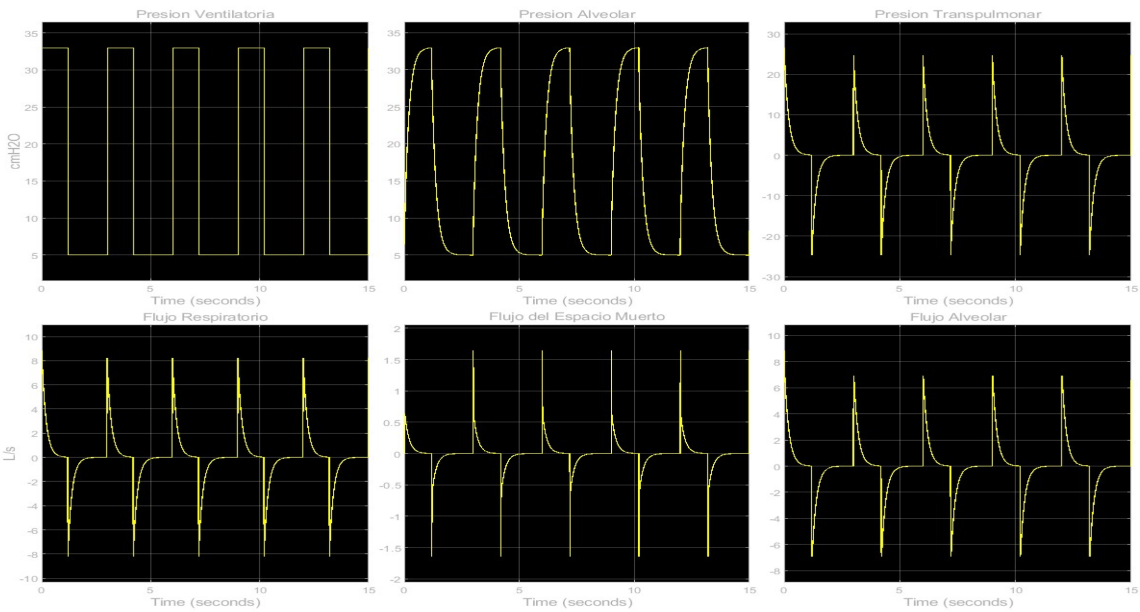

Figure 6: Simulation Results

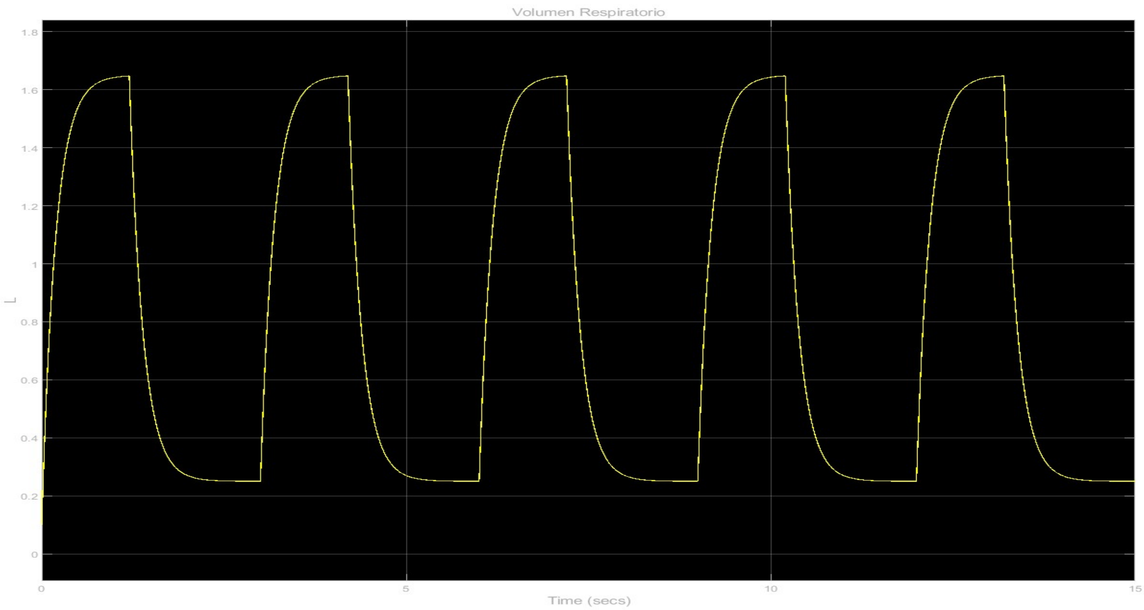

Figure 7: Simulation Results

I adjusted the ventilator settings to bring these values to a normal patient. The graphs I got from that are given below.

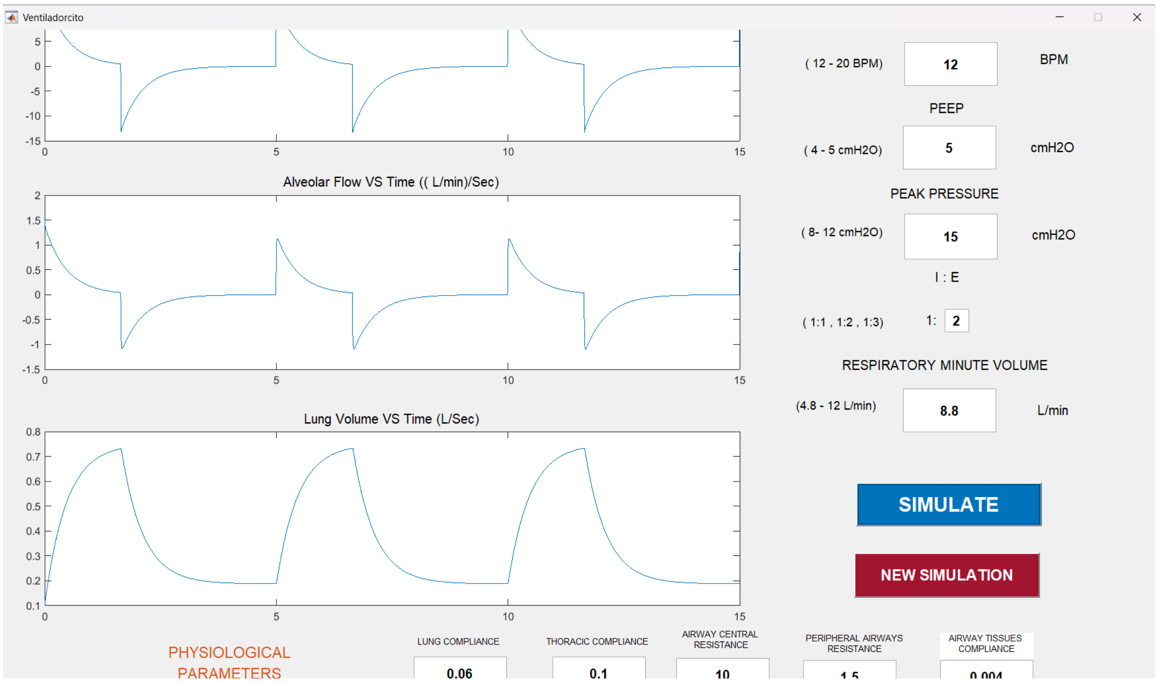

Figure 8: Graphs after ventilator settings are adjusted

6 Results for an Adult with an Obstructive Pulmonary Disease

In obstructive pulmonary diseases, air cannot get out of the lungs easily because the airways are narrowed or blocked. I have taken Asthma as the obstructive pulmonary disease of my choice.

The parameter values for an adult with Asthma are as follows:

- Lung compliance $= 0.03$ L/cm H_2O
- Thoracic compliance $= 0.05$ L/cm H_2O
- Airway central resistance $= 3$ cm H_2O/(L/s)
- Peripheral airway resistance $= 0.5$ cm H_2O/(L/s)
- Airway tissue compliance $= 0.002$ L/cm H_2O

The graphs I got from the simulation using the same ventilator parameters as a normal person are given below.

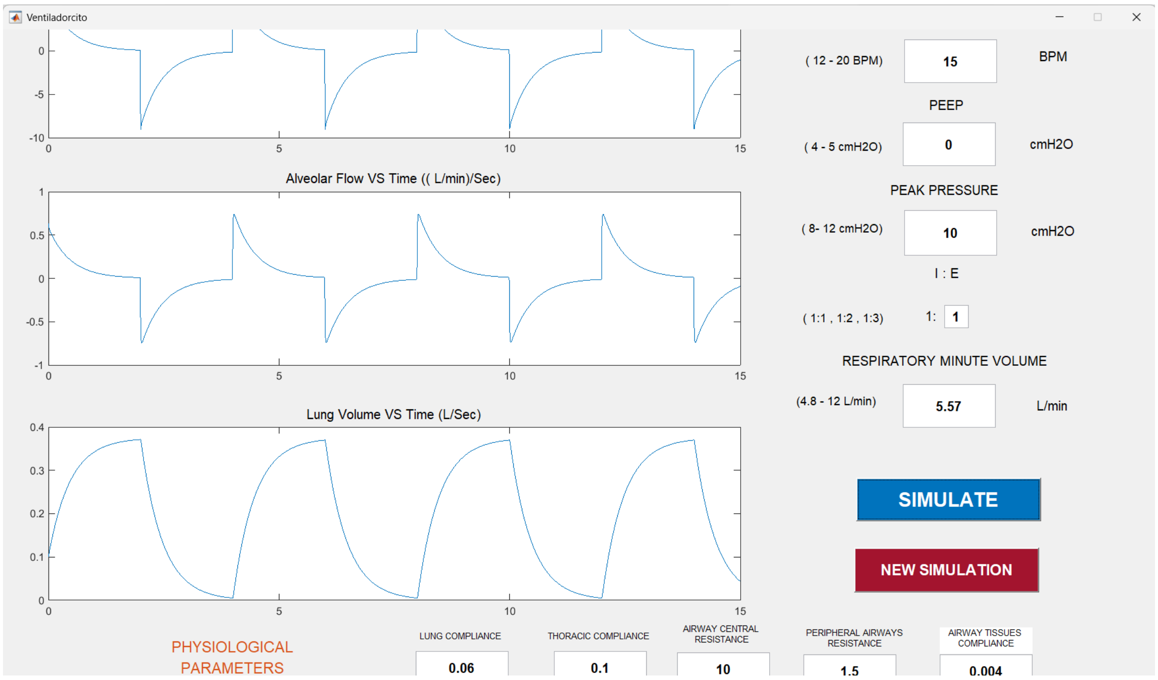

Figure 9: Simulation Results

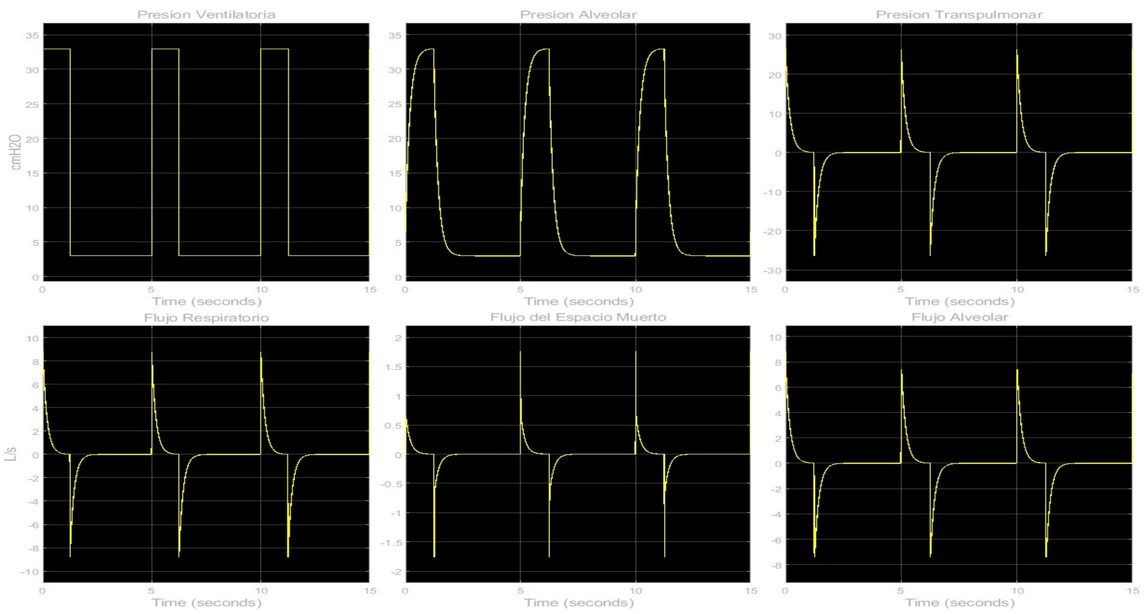

Figure 10: Simulation Results

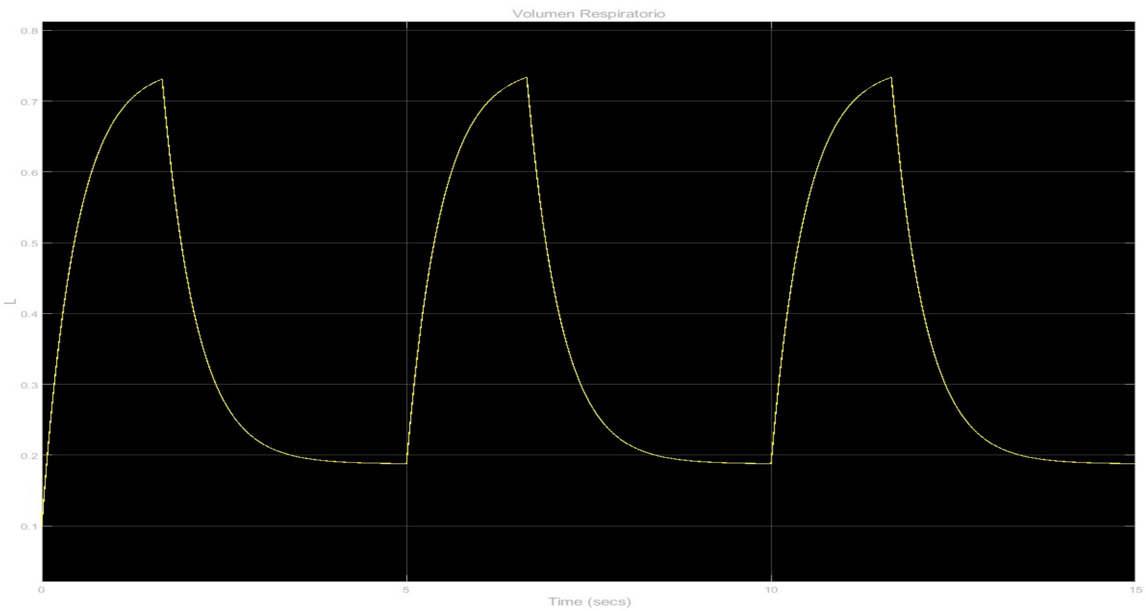

Figure 11: Simulation Results

I adjusted the ventilator settings to bring these values to a normal patient. The graphs I got from that are given below.

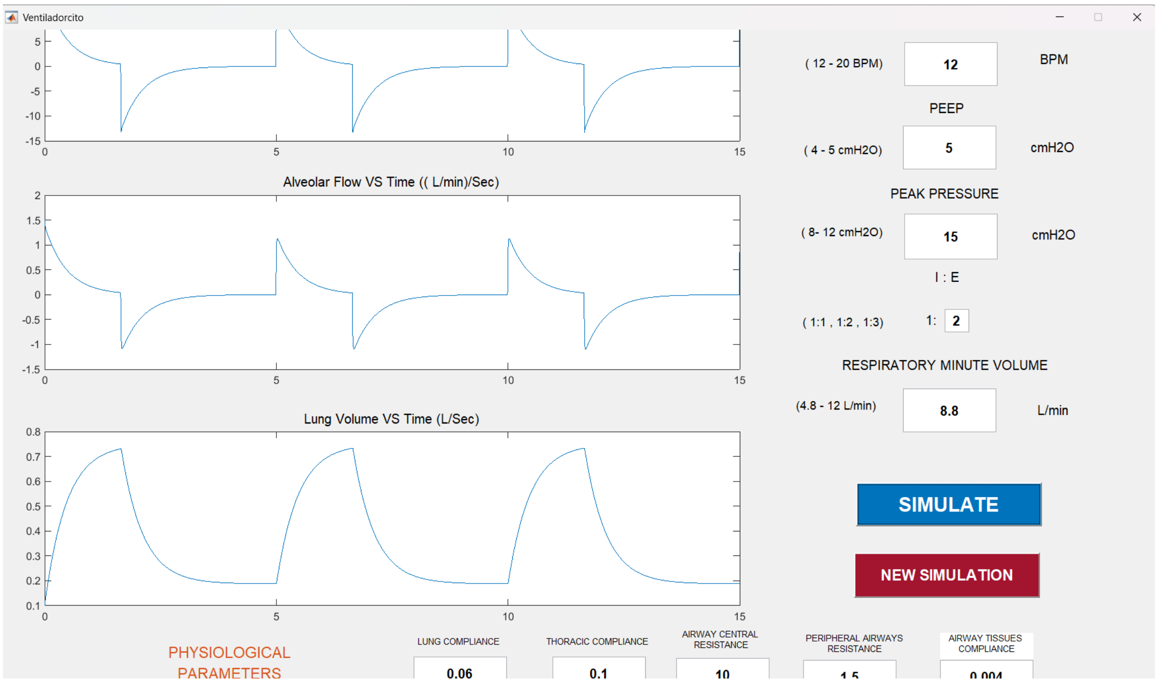

Figure 12: Graphs after ventilator settings are adjusted

7 Comparison

In the simulation of a healthy adult lung, minute ventilation remained within the expected physiological range of 5–8 L/min. This was due to the normal lung compliance and airway resistance values, which allowed the ventilator to deliver adequate tidal volume with each breath. As a result, the breathing cycle was well balanced, with efficient inspiration and expiration phases. The airflow and pressure-volume graphs demonstrated regular sinusoidal patterns, indicating stable and effective gas exchange without ventilatory strain.

In the case of pulmonary fibrosis, minute ventilation was notably decreased. The simulation modeled this condition by reducing lung compliance to reflect the stiff, fibrotic nature of the lung tissue. Although the ventilator settings remained unchanged, the stiffer lungs were unable to expand fully, resulting in reduced tidal volume. Consequently, the amount of air exchanged per minute dropped, posing a risk of hypoventilation. The pressure curves showed a steeper ascent, highlighting the increased effort required by the ventilator to deliver each breath, emphasizing the need for pressure or volume adjustments in clinical management.

For the obstructive condition modeled as asthma, minute ventilation appeared to remain within or slightly below the normal range. However, this was misleading, as elevated airway resistance led to air trapping and prolonged expiration phases. Although the tidal volume was relatively maintained, the delayed and incomplete exhalation caused a buildup of residual air in the lungs. This reduced the effectiveness of each subsequent breath and created a mismatch between ventilated and perfused lung areas. As a result, despite seemingly normal MV values, the overall gas exchange efficiency was compromised, indicating a risk of inadequate alveolar ventilation.

8 Conclusion

Across the three conditions, it was evident that identical ventilator settings produce very different outcomes depending on the patient's respiratory mechanics. Restrictive diseases primarily limit lung volume delivery, reducing minute ventilation, while obstructive diseases impair expiratory flow, leading to dynamic hyperinflation. These findings underscore the importance of individualized ventilator settings based on the pathophysiological profile of the patient.

References

[1] Vinícius Silva, "Simulation of Respiratory Mechanics on Simulink with GUI," MATLAB Central File Exchange. Available: `https://www.mathworks.com/matlabcentral/fileexchange/75335-simulation-of-respiratory-mechanics-on-simulink-with-gui`.