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A1: Simulation of Respiratory Mechanics

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BM2102 Modelling and Analysis of Physiological Systems

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Contents

1 Introduction

The report employs David Leonardo Rodriguez Sarmiento and Daniela Acevedo Guerrero's (2020) Simulation of Respiratory Mechanics using Simulink with GUI to examine the ventilation dynamics of an adult subjected to three simulated scenarios, which are, Healthy Respiratory Condition, Restrictive Pulmonary Disease, Obstructive Pulmonary Disease The study attempts to explain and graphically depict the variations in minute ventilation throughout these circumstances by maintaining consistent ventilator settings.

2 Healthy Respiratory Condition

Lung compliance, or the lungs' capacity to expand and contract with ease, is at its highest level and airway resistance is at its lowest in a healthy respiratory state. A harmonious and efficient respiratory process is facilitated by the well-balanced respiratory rate, tidal volume, and minute ventilation.

- Values for healthy person under normal conditions
  - Lung compliance = 0.1 L/cmH_2O
  - Thoracic compliance = 0.1 L/cmH_2O
  - Airway central resistance = 3 cmH_2O/(L/s)
  - Peripheral airways resistance = 0.5 cmH_2O/(L/s)
  - Airway tissue compliance = 0.005 L/cmH_2O
- The healthy person is connected to the ventilator under below mentioned conditions and the results are shown in the graphs
  - Breathing frequency = 15
  - PEEP value = 0 cmH_2O/(L/s)
  - Peak pressure = 10 cmH_2O/(L/s)
- Respiratory minute volume = 7.5 L/min

2.1 Simulation Outputs for Healthy Condition

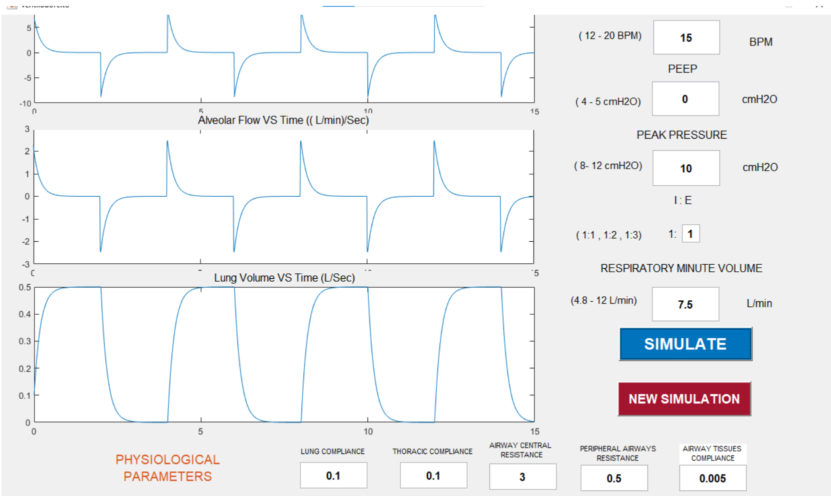

Figure 01: Ventilator settings GUI - Healthy Condition

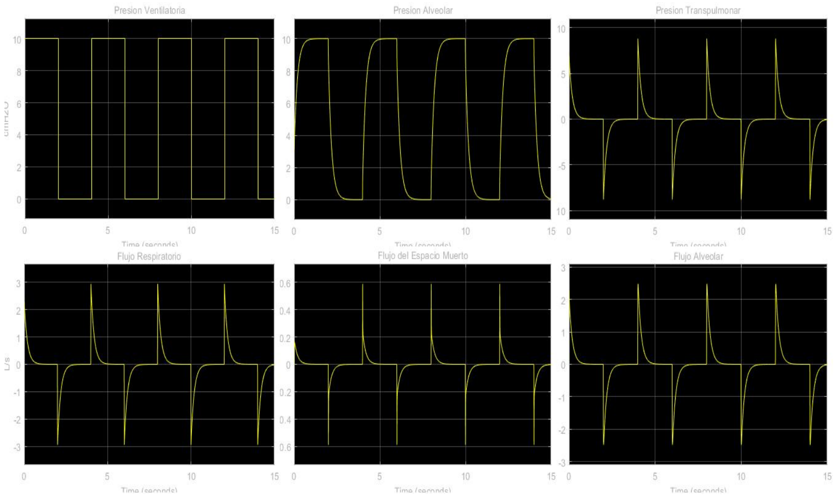

Figure 02: Output of Flow and Pressure Monitor - Healthy Condition

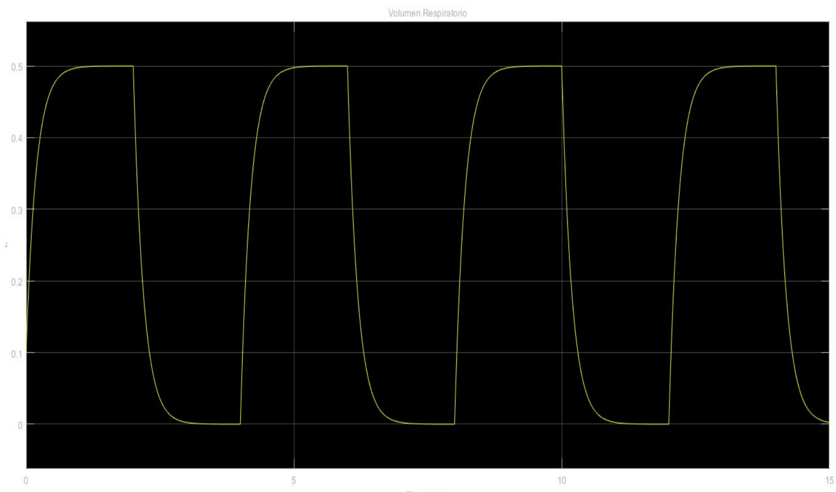

Figure 03: Output of Lung Volume Monitor - Healthy Condition

3 Restrictive Pulmonary Disease Condition

A collection of respiratory conditions together referred to as restrictive pulmonary disease are marked by a decrease in lung compliance. The ability of the lungs to expand and extend during inhalation is referred to as lung compliance. Due to changes in the chest wall and lung parenchyma, this compliance is greatly reduced in restrictive pulmonary disorders.

Lung compliance is the hallmark effect of restrictive pulmonary disorders. When breathing, the lung tissue stiffens and loses some of its elasticity, making it more difficult for the lung to expand completely and hold in air. Changes like fibrosis or scarring inside the lung parenchyma, which restrict the lungs' natural capacity to stretch, are frequently blamed for this decline in compliance.

Thoracic compliance may be impacted in restrictive pulmonary illnesses, much as lung compliance. The ribcage, which is made up of the chest wall and ribs, plays a role in the respiratory system's overall compliance. The decreased thoracic compliance observed in these situations may also be attributed to abnormalities in the chest wall, such as stiffness or deformities.

Restrictive pulmonary disorders may not directly impact the compliance of airway tissues, including those of the central and peripheral airways. The primary indication of these disorders is in the lung parenchyma and chest wall, with minimal direct influence on the airway tissues' compliance.

3.1 What is Asbestosis

People who breathe in asbestos fibers and dust for an extended length of time can get Asbestosis, a lung illness. The mineral asbestos produces long-lasting, minuscule fibers. Fibrosis, or the thickening and scarring of the lungs, can be brought on by asbestos fibers and dust entering the lungs. Additionally, asbestos can thicken the pleura, the membrane that surrounds your lungs. Breathing may become challenging as a result of this lung tissue damage and thickness. Reduced lung capacities, a restrictive ventilatory defect, poor gas exchange, and an increased sensation of dyspnea during physical activity are all consequences of these fibrotic alterations.

- A decrease in lung compliance brought on by fibrosis and scarring characterizes the changes in lung function seen in Asbestosis . Hence give the below values
  - Lung compliance = 0.08 L/cmH_2O
  - Thoracic compliance = 0.05 L/cmH_2O
  - Airway central resistance = 3 cmH_2O/(L/s)
  - Peripheral airways resistance = 5 cmH_2O/(L/s)
  - Airway tissue compliance = 0.005 L/cmH_2O

3.2 Simulation Outputs for Asbestosis

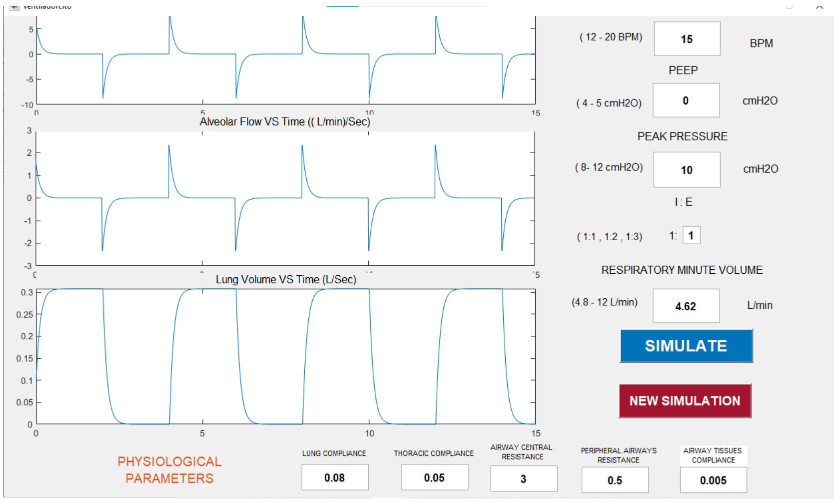

Figure 04: Ventilator settings GUI - Asbestosis

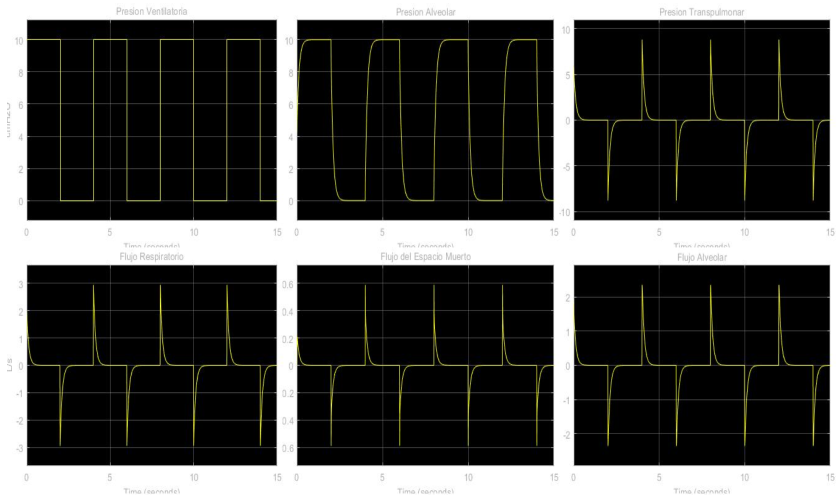

Figure 05: Output of Flow and Pressure Monitor - Asbestosis

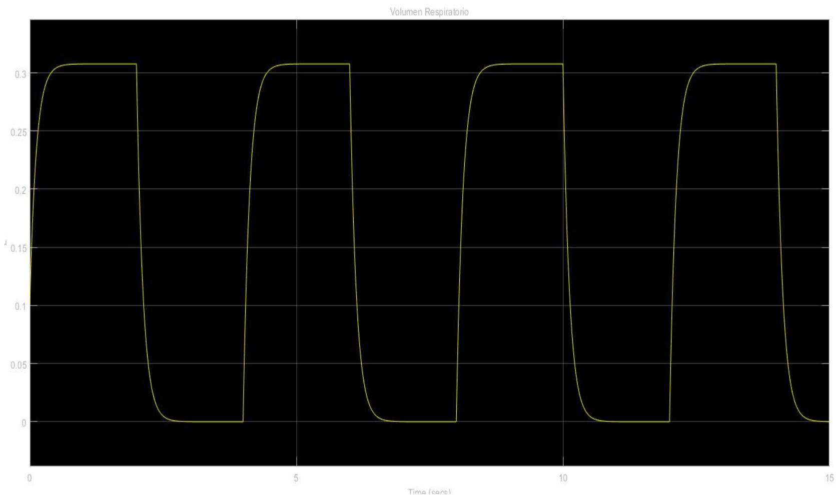

Figure 06: Output of Lung Volume Monitor - Asbestosis

4 Obstructive Pulmonary Disease Condition

Airflow limitation resulting from increased resistance during exhalation is a characteristic of obstructive lung disorders, including asthma and chronic obstructive pulmonary disease (COPD).

In patients with obstructive pulmonary disorders, thoracic compliance typically increases. This is because people who suffer from diseases like asthma or chronic obstructive pulmonary disease (COPD) frequently engage their accessory chest muscles to help breathe, which increases the compliance of the chest wall. In obstructive lung illnesses, lung compliance also rises. The lungs' hyperinflation is the cause of this rise in lung compliance.

These disorders cause bronchoconstriction and chronic inflammation, which raise resistance in the central airways and make it harder for air to pass through during inhalation and, especially, expiration. The typical airflow restriction seen in obstructive diseases is mostly caused by this increased resistance.

In obstructive pulmonary illnesses, peripheral airways resistance is also affected, particularly in conditions like asthma when bronchoconstriction reaches the smaller airways. Airflow through the respiratory system is impeded by the constriction of these peripheral airways, which adds to the system's increased resistance.

The thickening and increased production of mucus in the airway walls are structural alterations that lead to a decrease in the compliance of the airway tissues. This decreased compliance may make airflow restriction worse and impair breathing's natural processes.

4.1 What is Pulmonary Emphysema

Emphysema is a long-term lung disease that has several effects on the alveoli, or air sacs. A number of alterations, such as collapse, destruction, narrowing, overinflation, and stretching, may occur in the air sacs. Breathlessness and a reduction in respiratory function are brought on by the overinflation, which is the consequence of the alveolar walls breaking down. Sadly, the damage to the air sacs is irreversible, leaving the lower lung tissue with permanent holes in it. Within the category of chronic obstructive pulmonary disease (COPD), a collection of lung disorders marked by breathing difficulty and airflow obstruction, is pulmonary emphysema.

- The blockages caused by lung expansion and alveolar injury are shown by the changes in values below
  - Lung compliance = 0.4 L/cmH_2O
  - Thoracic compliance = 0.1 L/cmH_2O
  - Airway central resistance = 3 cmH_2O/(L/s)
  - Peripheral airways resistance = 5 cmH_2O/(L/s)
  - Airway tissue compliance = 0.005 L/cmH_2O

4.2 Simulation Outputs for Pulmonary Emphysema

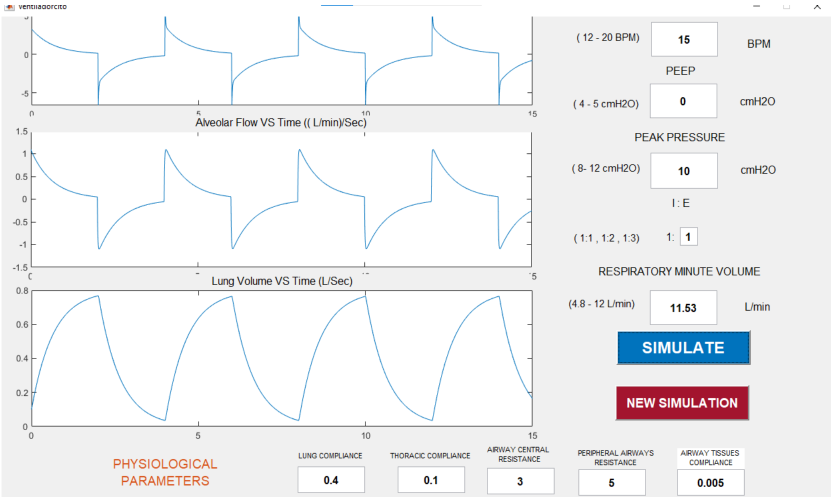

Figure 07: Ventilator settings GUI - Pulmonary Emphysema

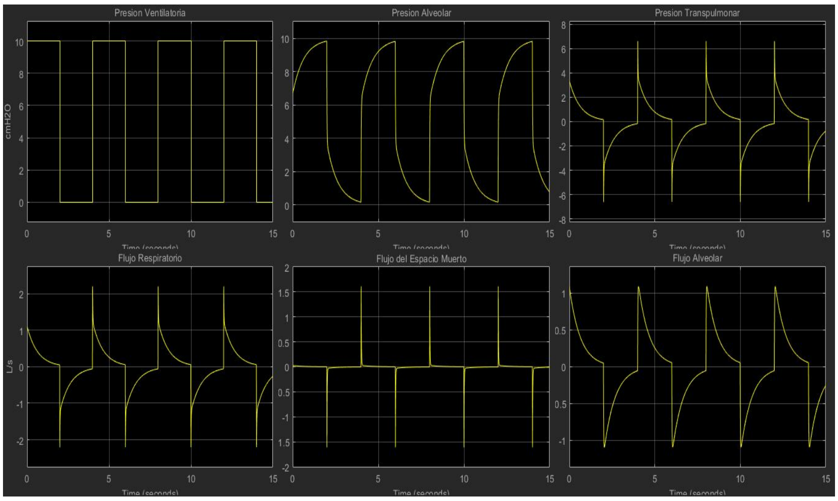

Figure 08: Output of Flow and Pressure Monitor - Pulmonary Emphysema

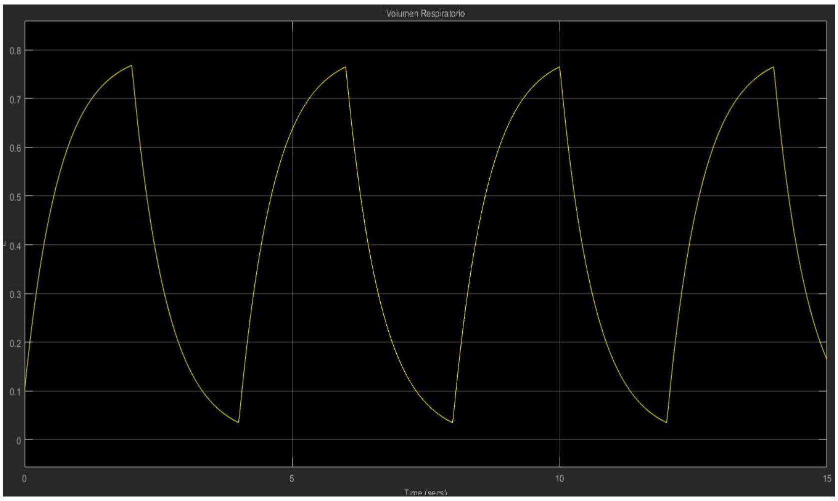

Figure 09: Output of Lung Volume Monitor - Pulmonary Emphysema

5 Adjusting Ventilator Setting to Accomodate Breathing

5.1 Pulmonary Emphysema

Ventilator settings for pulmonary emphysema patients should be carefully modified to minimize the risk of barotrauma while maintaining adequate breathing.

- Breathing frequency = 15
- PEEP value = 5 $cmH_2O/(L/s)$ - to avoid collapsing the airway
- Peak pressure = 10 $cmH_2O/(L/s)$ - To overcome increasing airway resistance
- I:E = 1:3 - To help avoid hyperinflation, use prolonged expiratory phase

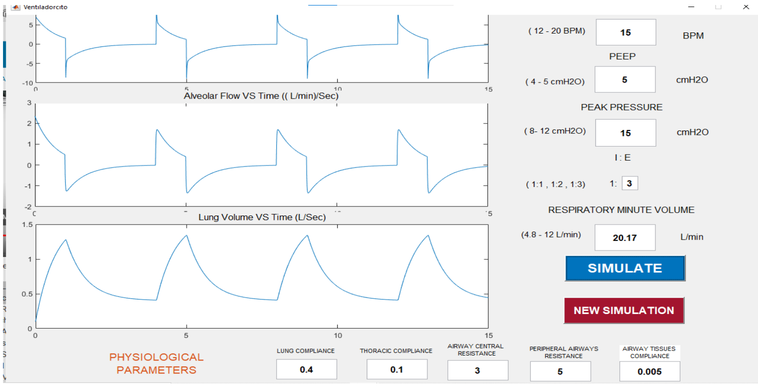

Figure 10: Results after adjusting ventilator settings to accomodate breathing for Pulmonary Emphysema patient

5.2 Asbestosis

A patient with asbestosis may require appropriate breathing while avoiding excessive airway pressure due to their lower lung compliance and possibly restrictive ventilatory abnormalities.

- Breathing frequency = 15
- PEEP value = 5 $cmH_2O/(L/s)$ - To sustain lung recruitment and stop the alveoli from collapsing at the end of expiration.
- Peak pressure = 10 $cmH_2O/(L/s)$ - to guarantee delivery of an adequate tidal volume
- I:E = 1:1 - to avoid prolonged expiration

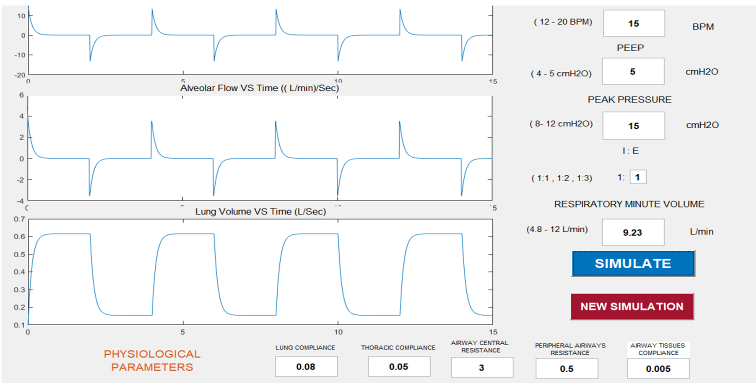

Figure 11: Results after adjusting ventilator settings to accomodate breathing for Asbestosis patient

6 Differences in minute ventilation for the same setting of the ventilator

Minute Ventilation = Tidal Volume (TV) X Respiratory Rate(RR)

Variations in lung function and respiratory mechanics can account for the disparities in minute ventilation levels amongst people with various pulmonary diseases.

- Healthy Person - Minute Ventilation = 7.5 L/min
  In a healthy person, the ideal minute ventilation is influenced by both respiratory rate and tidal volume. A balanced minute ventilation value results from efficient air exchange made possible by adequate lung compliance and airway function. The respiratory system functions well in the absence of major obstructions or restrictions.

- Restrictive Pulmonary Disease - Minute Ventilation = 4.62 L/min
  The lungs stiffen under these circumstances, making it difficult to inhale at a normal tidal volume. In order to make up for this, the person increases their breathing rate, which lowers their minute ventilation.The volume of air that can be drawn in and exhaled with each breath is restricted by the reduced lung compliance.

- Obstructive Pulmonary Disease - Minute Ventilation = 11.53 L/min,
  Increased airway resistance in obstructive illnesses prevents air from leaving the body smoothly during exhalation, which results in an incomplete lung emptying. People frequently raise their breathing rate while maintaining a normal or raised tidal volume to make up for this, which raises their minute ventilation. In order to overcome the airflow restriction and expel enough air, the respiratory rate is increased.

Additional reasons for the variation in minute ventilation.

- Patient Effort - The efficiency of breathing may be impacted by the patient's level of effort or respiratory muscle strength. Individuals who suffer from neuromuscular disorders or weak respiratory muscles may find it difficult to breathe comfortably.

- Anatomical Variations - Anatomical variations in the anatomy of the airways can affect airflow. The resistance to airflow can be impacted by ailments such upper airway blockages or tracheal stenosis.

- Auto PEEP(Intrinsic PEEP) - a condition in which patients experience air being held in their lungs at the end of expiration. This may have an impact on ventilation and raise the effective PEEP.

7 Conclusion

In conlcusion, this report explores the complexities of respiratory dynamics by investigating healthy conditions and modeling scenarios related to Obstructive Pulmonary Disease (Pulmonary Emphysema) and Restrictive Pulmonary Disease (Asbestosis). Through the examination of lung compliance, airway resistance, and patient effort, the rport clarifies the variations in minute ventilation that occur in people with various lung conditions.

8 References

1. `https://my.clevelandclinic.org/health/diseases/22245-asbestosis`
2. `https://www.hopkinsmedicine.org/health/conditions-and-diseases/pulmonary-emphysema#:~:text=Pulmonary%20emphysema%20is%20a%20chronic,most%20often%20caused%20by%20smoking.`