University of Moratuwa
Faculty of Engineering
Department of Electronic & Telecommunication Engineering

17th of April, 2025

BM2102: Modelling and Analysis of Physiological Systems

A1: Simulation of Respiratory Mechanics

By: Fernando S.R.N.

220169V

Contents

1 Introduction

The mechanics of respiration plays an important role when trying to understand the function of the lungs and how various diseases impact breathing. In this assignment a MATLAB-based simulator is used to model and analyze different respiratory conditions. The main conditions which will be analyzed are,

- Normal pulmonary function
- Restrictive pulmonary disease condition
- Obstructive pulmonary disease condition

2 Respiratory Model and Parameters

The respiratory model used can be represented as below:

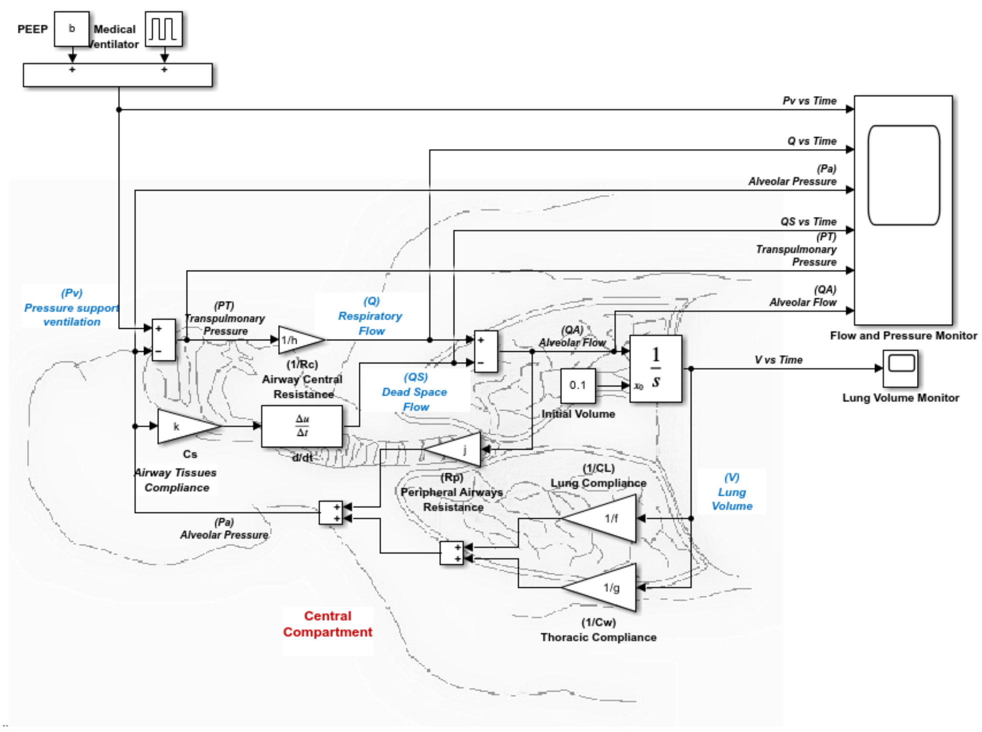

Figure 1: Representation of Model

The above model consists representations of both central and peripheral airway physiological parameters. And the main parameters which are used in the simulator are listed below:

- **Breathing frequency:** Number of breaths taken in one minute
- **PEEP (Positive End-Expiratory Pressure):** The pressure in the lungs at the end of expiration to keep the alveoli open
- **Peak Pressure:** The pressure achieved during inspiration when the air is being pushed into the lungs
- **Elasticity (E):** A measure of the stiffness of the respiratory system, calculated as the reciprocal of compliance
- **Respiratory Minute Volume (minute ventilation):** The total volume of air entering or leaving the lungs per minute, can be calculated as,
  tidal volume × respiratory rate
- **Lung Compliance:** The ability of the lungs to stretch and expand, defined as the change in lung volume per unit change in pressure
- **Thoracic Compliance:** The compliance of the thoracic cavity, which is how easily the chest wall expands
- **Airway Resistance:** The resistance to airflow within the airways, affecting the effort needed to ventilate the lungs
- **Airway Tissue Compliance:** The compliance of the tissue surrounding the airway, represents how easily it stretches during ventilation

The parameters above include the settings of the ventilator which will simulate the breathing process and also the physiological parameters of the lungs.

The ventilator parameters will be kept as below for all simulating conditions,

- Breathing frequency: 10 BPM
- PEEP: 0 cmH2O
- Peak pressure: 10 cmH2O

3 Simulation of Normal Respiratory Conditions

The parameters below represent the respiratory behavior of a healthy person.

- Lung compliance: 0.1 L/cmH_2O
- Thoracic compliance: 0.1 L/cmH_2O
- Airway central resistance: 3 cmH_2O/L/s
- Peripheral airway resistance: 0.5 cmH_2O/L/s
- Airway tissue compliance: 0.005 L/cmH_2O

The resulting graphs of the above simulation are shown below,

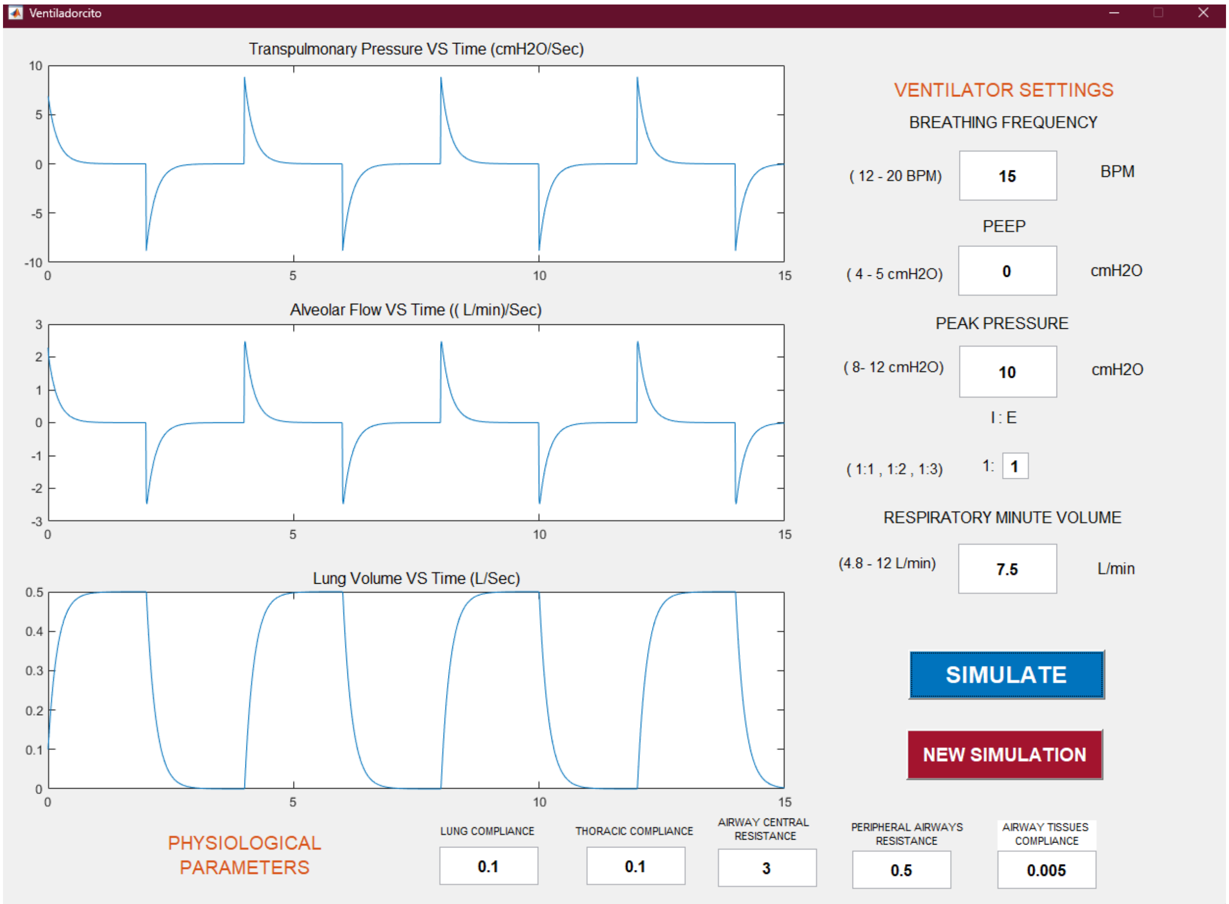

Figure 2: Graphs representing normal respiratory conditions

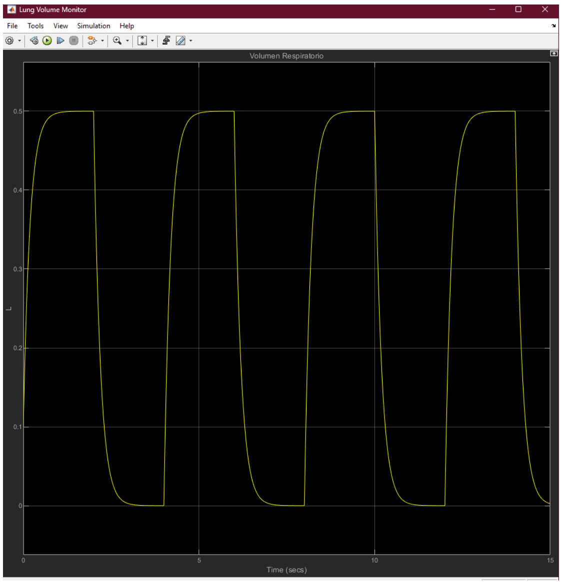

Figure 3: Graph of lung volume

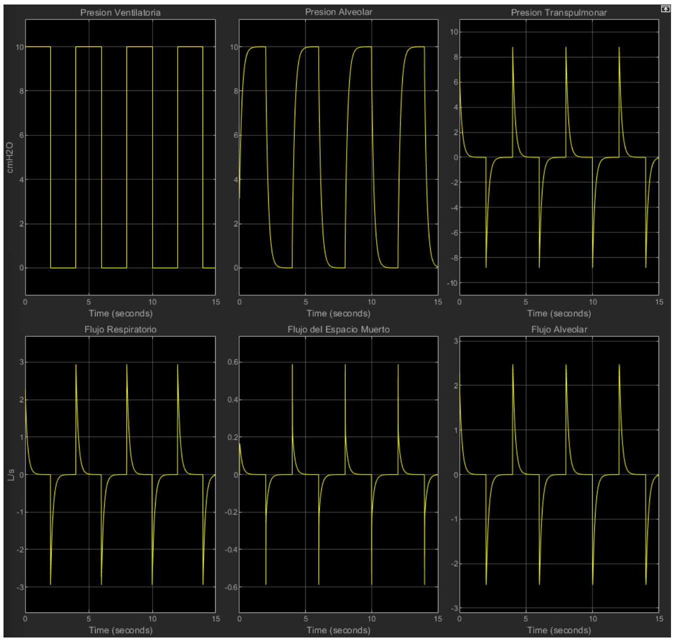

Figure 4: Graphs of Ventilator Pressure, Alveolar Pressure, Transpulmonary Pressure, Respiratory Flow, Dead Space Flow, Alveolar Flow

4 Simulation of Restrictive Pulmonary Disease Conditions

Restrictive pulmonary diseases are conditions that limit the lung's ability to fully expand, reducing lung volumes and making it difficult for the person to inhale enough air. This can result from stiffness in the lungs or issues with the chest wall, respiratory muscles, or nerves. Lung compliance is the main parameter affected by these types of diseases.

One common restrictive pulmonary disease is **Pulmonary Fibrosis**, which involves the formation of scar tissue (fibrosis) within the lungs. This scarring stiffens the lung tissue, reducing its elasticity and impairing gas exchange. Patients with this disease have progressive shortness of breath and a persistent dry cough. Pulmonary fibrosis can result from long-term exposure to harmful substances and autoimmune diseases.

The physiological parameters below represent the respiratory behavior of a person having Pulmonary Fibrosis.

- Lung compliance: 0.05 L/cmH_2O
- Thoracic compliance: 0.08 L/cmH_2O
- Airway central resistance: 2.5 cmH_2O/L/s
- Peripheral airway resistance: 0.5 cmH_2O/L/s
- Airway tissue compliance: 0.004 L/cmH_2O

We can observe that the respiratory minute volume has **decreased** compared to a normal person from the results below.

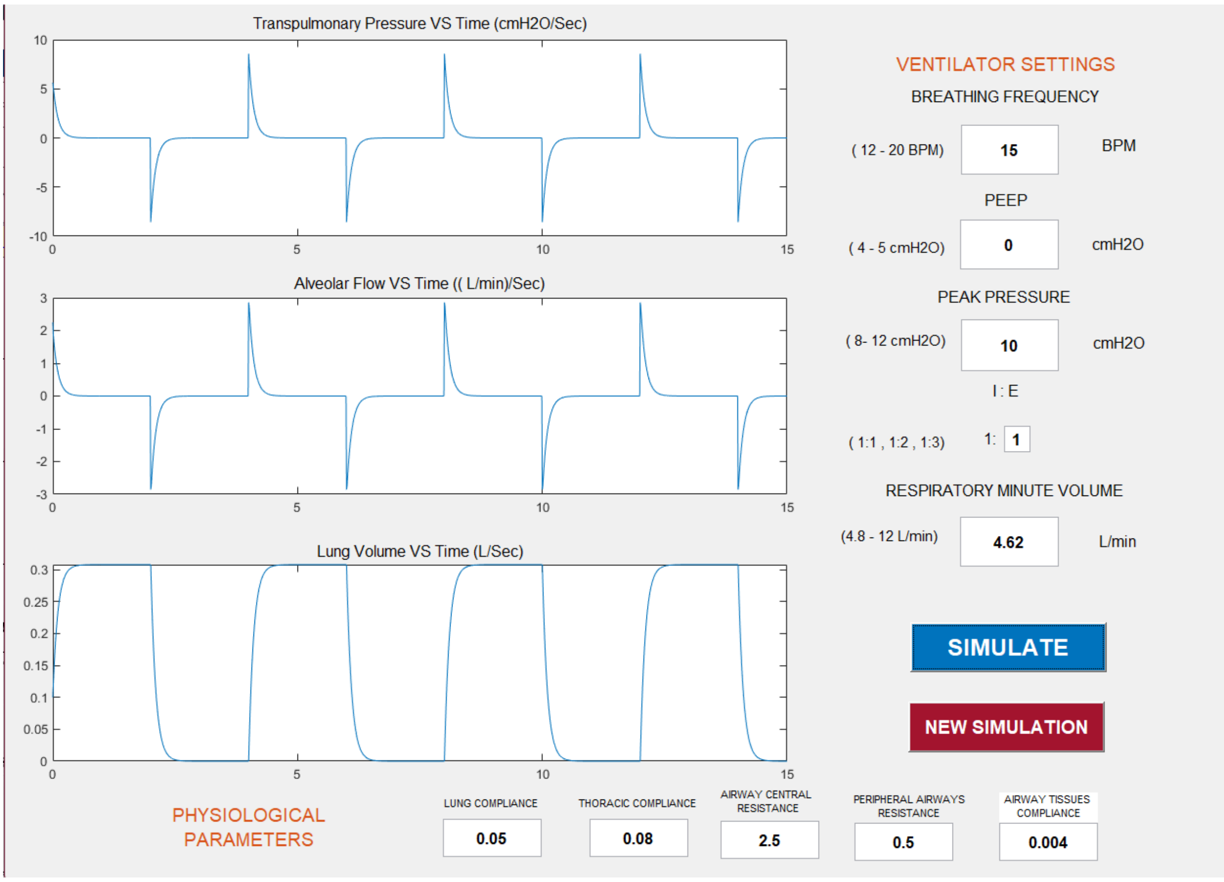

Figure 5: Graphs representing restrictive pulmonary disease condition

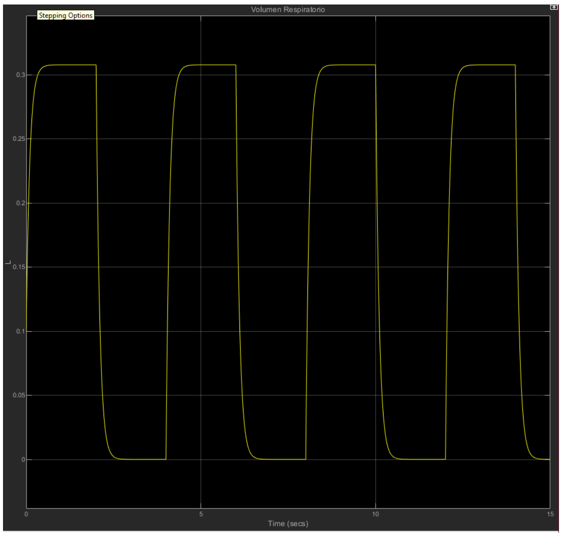

Figure 6: Graph of lung volume

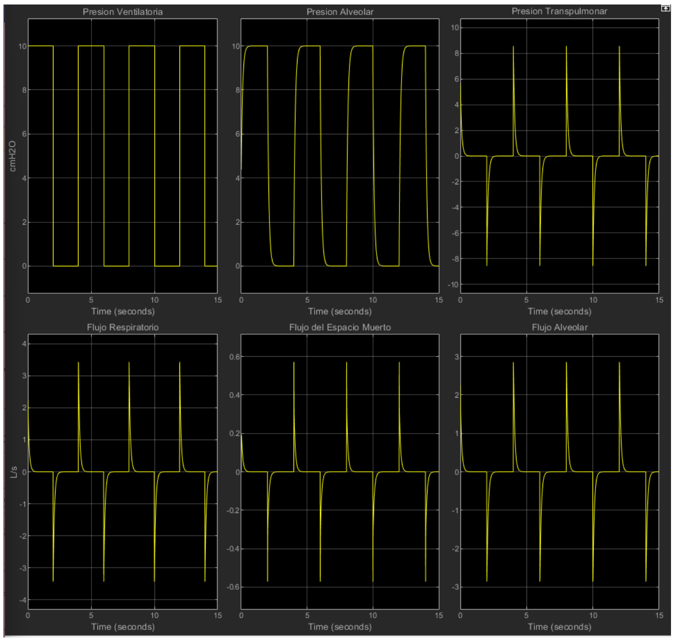

Figure 7: Graphs of Ventilator Pressure, Alveolar Pressure, Transpulmonary Pressure, Respiratory Flow, Dead Space Flow, Alveolar Flow

5 Simulation of Obstructive Pulmonary Disease Conditions

Obstructive pulmonary diseases are characterized by difficulty in exhaling air from the lungs due to narrowed or blocked airways. The main physiological parameters affected by this condition are central and peripheral airway resistances which increase significantly.

A common obstructive pulmonary disease is asthma, a chronic condition which results in airway inflammation, bronchoconstriction, and increased mucus production. These changes cause symptoms such as wheezing, coughing, chest tightness, and breathlessness. Asthma symptoms are often reversible with medications.

The physiological parameters below represent the respiratory behavior of a person having Asthma.

- Lung compliance: 0.4 L/cmH_2O
- Thoracic compliance: 0.1 L/cmH_2O
- Airway central resistance: 5 cmH_2O/L/s
- Peripheral airway resistance: 3 cmH_2O/L/s
- Airway tissue compliance: 0.005 L/cmH_2O

We can observe that the respiratory minute volume has **increased** compared to a normal person from the results below.

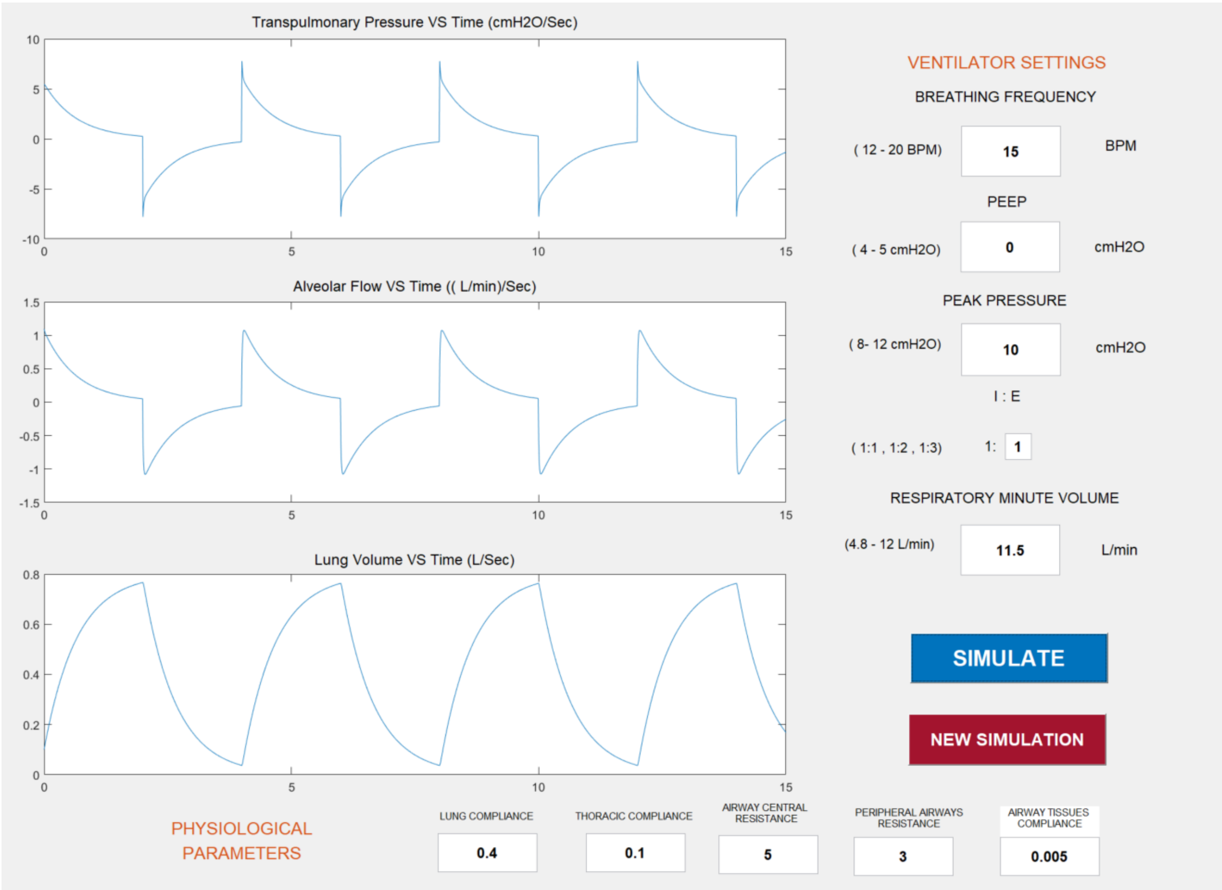

Figure 8: Graphs representing obstructive pulmonary disease condition

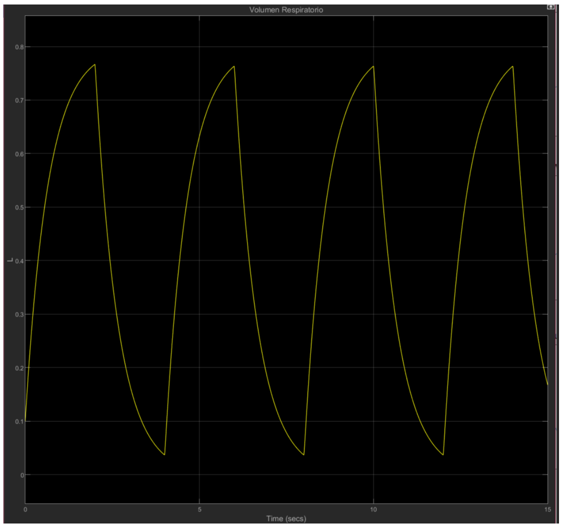

Figure 9: Graph of lung volume

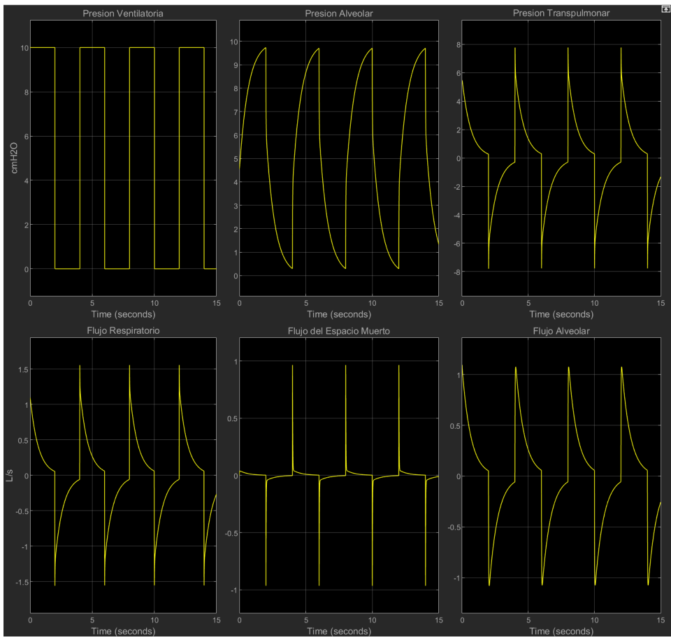

Figure 10: Graphs for Ventilator Pressure, Alveolar Pressure, Transpulmonary Pressure, Respiratory Flow, Dead Space Flow, Alveolar Flow

6 Comparison of Minute Ventilation for All Conditions

Minute ventilation is the total volume of air entering or leaving the lungs per minute. It is calculated as the product of tidal volume and respiratory rate. This value is crucial in assessing how effectively a patient is breathing.

$$\text{Minute Ventilation} = \text{Respiratory Rate} \times \text{Tidal Volume}$$

The minute ventilation values obtained under different respiatory conditions are as follows:

- **Normal:** 7.50 L/min
- **Restrictive (Pulmonary Fibrosis):** 4.62 L/min
- **Obstructive (Asthma):** 11.5 L/min

As observed, minute ventilation significantly decreases in restrictive lung disease due to reduced lung compliance. In obstructive disease such as asthma, although airway resistance increases, the body may compensate by increasing respiratory effort, resulting in an even higher minute ventilation compared to the normal case. This reflects the increased work of breathing and the mechanisms that the respiratory system employs to maintain adequate gas exchange.

References

- David Leonardo Rodriguez Sarmiento and Daniela Acevedo Guerrero (2020). Simulation of Respiratory Mechanics on Simulink with GUI
- Benjamin J. Delgado; Tushar Bajaj.Physiology,Lung Capacity
- Lutfi, M.F. The physiological basis and clinical significance of lung volume measurements. Multidiscip Respir Med 12, 3 (2017).