Department of Electronic and Telecommunications Engineering

BM2102 Modelling and Analysis of Physiological Systems

Assignment 1

Simulation of Respiratory Mechanics

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Contents

1 Introduction

The behaviour of the human respiratory system can be modelled using modern modelling software with the inclusion of essential pulmonary characteristic parameters. Such an attempt is published and open-sourced by [1] as a MATLAB Simulink project. This report discusses the behaviour of three main pulmonary conditions, simulated with the help of the above Simulink model. The overview of the respiratory model is shown below.

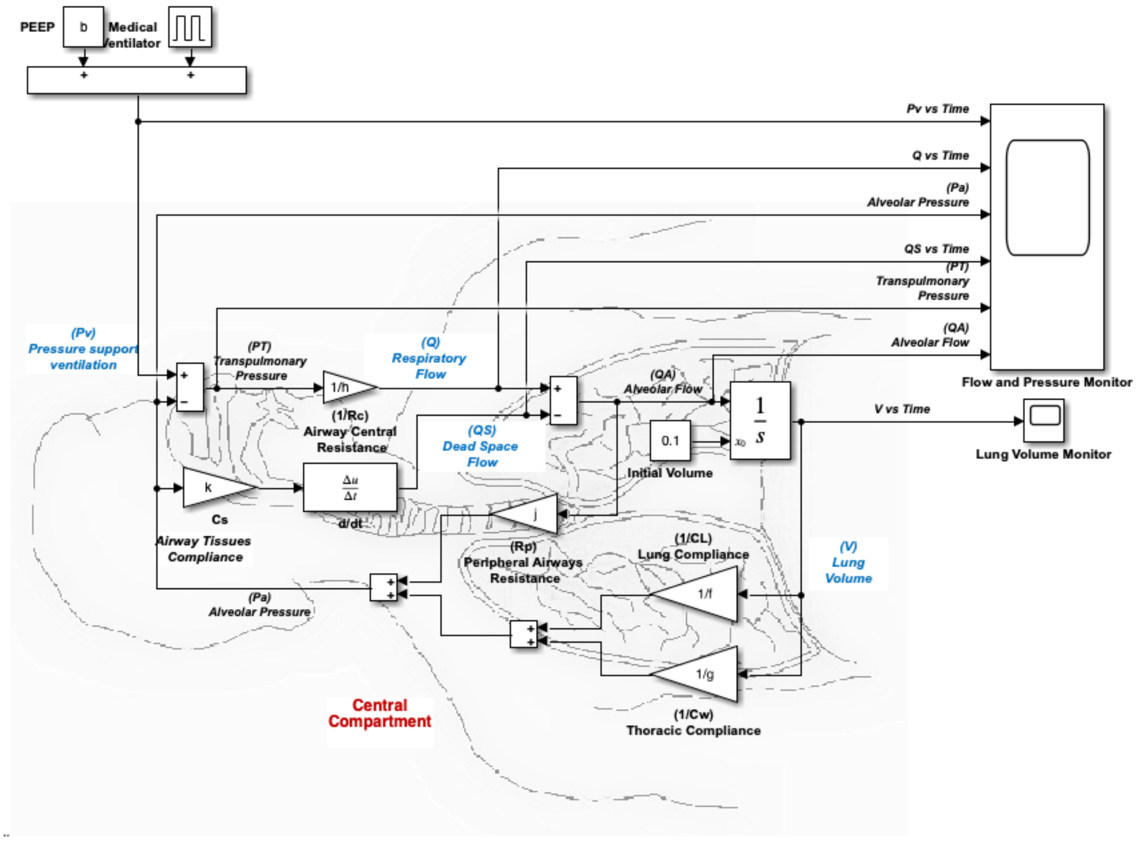

Figure 1: Overview of the respiratory system model. The system can be divided into two main parts; Central airway and peripheral airways.

2 Important model parameters

The above system overview shows some visible parameters. Both the central and peripheral airways have resistances to airflow, noted by **h** and **j** respectively. There are also parameters such as **alveolar volume** and **dead space volume**. However, the GUI window enables setting of the following key variables.

2.1 Physiological parameters

These are used to model the physiological features of the lungs.

1. **Lung compliance** - A measure of expansive ability of lungs
2. **Thoracic compliance** - A measure of expansive ability of thorax
3. **Airway central resistance** - Resistance to airflow in the central part (Trachea)
4. **Peripheral airway resistance** - Resistance to airflow in the peripheral parts (Bronchi, bronchioles)
5. **Airway tissue compliance** - A measure of expansive ability of tissues in airways

2.2 Ventilator parameters

This system does not model the diaphragm, but instead uses an external ventilator to carry out the inhale-exhale process. Following are the settings which can be used to tune variables such as breathing rate.

1. **Breathing frequency** - The rate at which inhaling and exhaling is done
2. **PEEP(Positive End-Expiratory Pressure** - Airway pressure at end of exhalation
3. **Peak pressure** - Maximum airway pressure at inhalation.

3 Simulation for normal conditions

As demonstrated in [2], we will set the physiological parameters to the following value in-order to simulate the pulmonary behaviour of a normal healthy person.

Lung compliance	0.1 $L/cmH2O$
Thoracic compliance	0.1 $L/cmH2O$
Airway central resistance	0.3 $cmH2O/L/s$
Peripheral airway resistance	0.5 $cmH2O/L/s$
Airway tissue compliance	0.005 $L/cmH2O$

The **ventilator settings** will be kept constant as follows for simulations of all three conditions.

Breathing frequency	10 BPM
PEEP	0 $cmH2O$
Peak pressure	0.3 $cmH2O$

The results of the simulation are as follows

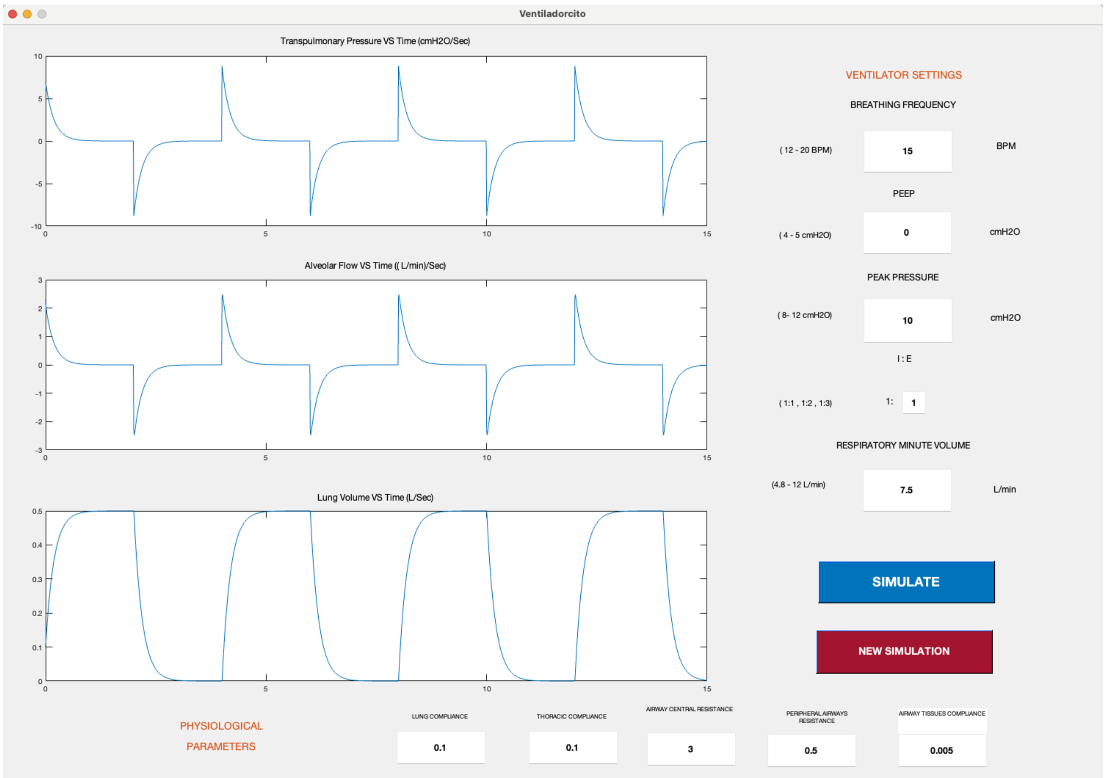

Figure 2: The graphs obtained under normal pulmonary conditions. **Respiratory minute volume** is recorded as 7.5 L/min. Peak lung volume is 0.5 L/sec.

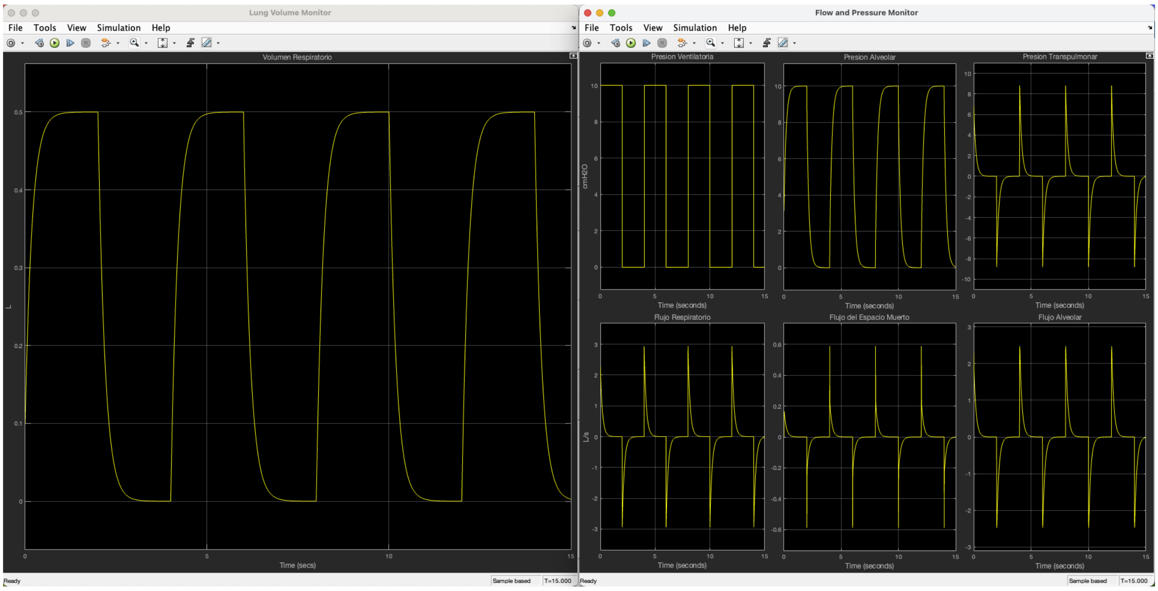

Figure 3: Detailed graphs for lung volume, flow and pressure variables for the restrictive pulmonary disease state.

4 Simulation for restrictive pulmonary disease conditions

Restrictive Pulmonary Diseases are characterized by the reduction in a subject's overall lung volume and elasticity. This may be caused due to reduction in pulmonary compliance (reduction of elascticity of lungs) or thoracic compliance (reduction of expanding ability of chest wall).

Asbestosis is an example of such a restrictive pulmonary condition which result in physiological parameters equivalent to the below.

Lung compliance	0.05 $L/cmH2O$
Thoracic compliance	0.05 $L/cmH2O$
Airway central resistance	0.3 $cmH2O/L/s$
Peripheral airway resistance	0.3 $cmH2O/L/s$
Airway tissue compliance	0.005 $L/cmH2O$

The simulation will be done considering the above values with the ventilator settings kept constant.

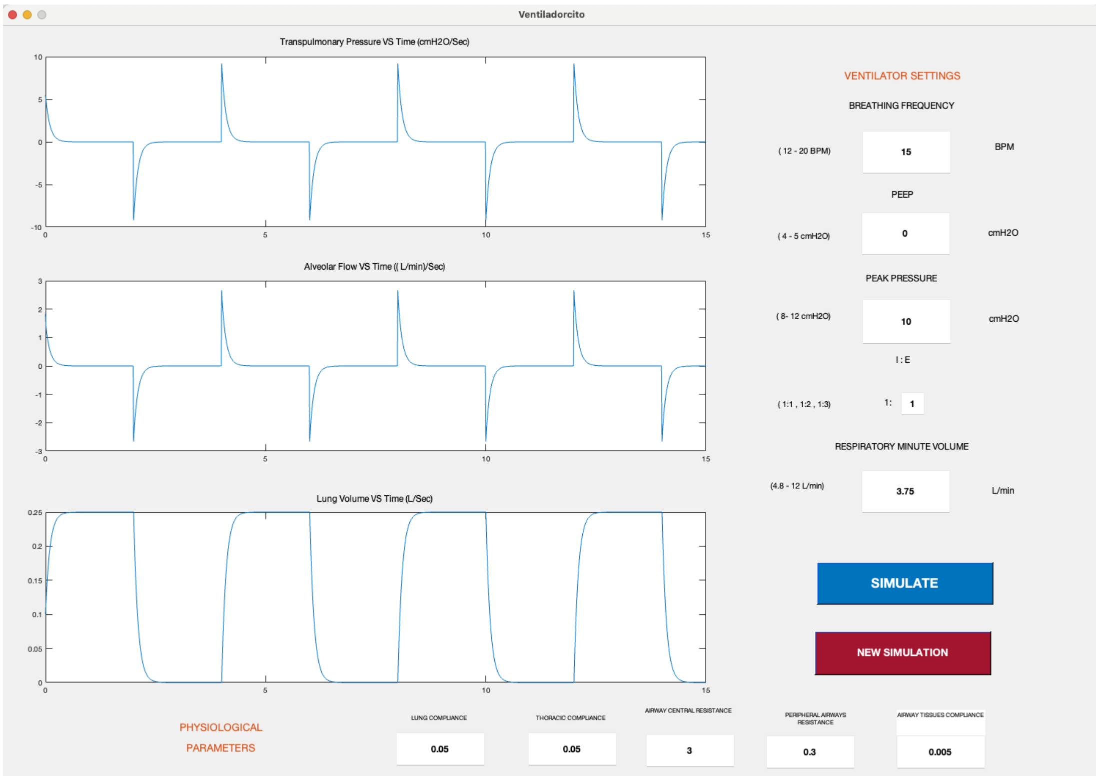

Figure 4: The graphs obtained under restrictive pulmonary disease conditions. **Respiratory minute volume** is recorded as 3.75 L/min. It has been reduced. Furthermore, we can observe that peak lung volume has reduced to 0.25 L/sec.

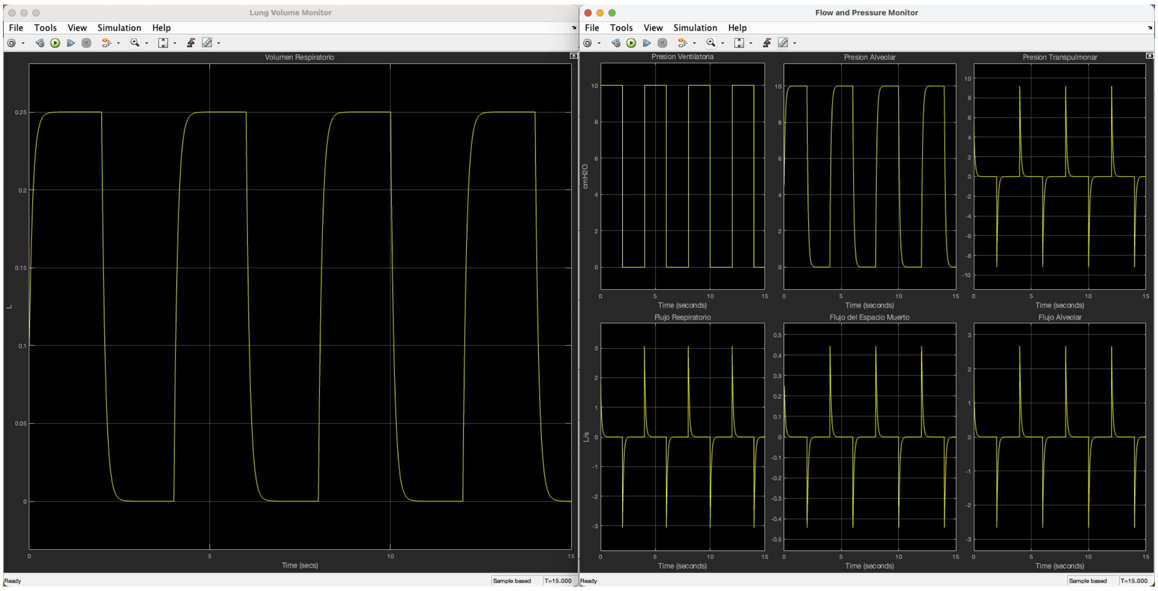

Figure 5: Detailed graphs for lung volume, flow and pressure variables.

5 Simulation for obstructive pulmonary disease conditions

As the name suggests, obstructive pulmonary conditions lead to a state og higher resistance in air flows. Some examples for this conditions are **asthma, bronchitis and emphysema**. The following physiological parameters closely resemble **asthma** where both central and peripheral airway resistances are increased.

Lung compliance	0.4 $L/cmH2O$
Thoracic compliance	0.1 $L/cmH2O$
Airway central resistance	3 $cmH2O/L/s$
Peripheral airway resistance	5 $cmH2O/L/s$
Airway tissue compliance	0.005 $L/cmH2O$

The simulation follows with ventilator settings being kept constant. The results are shown on the next page.

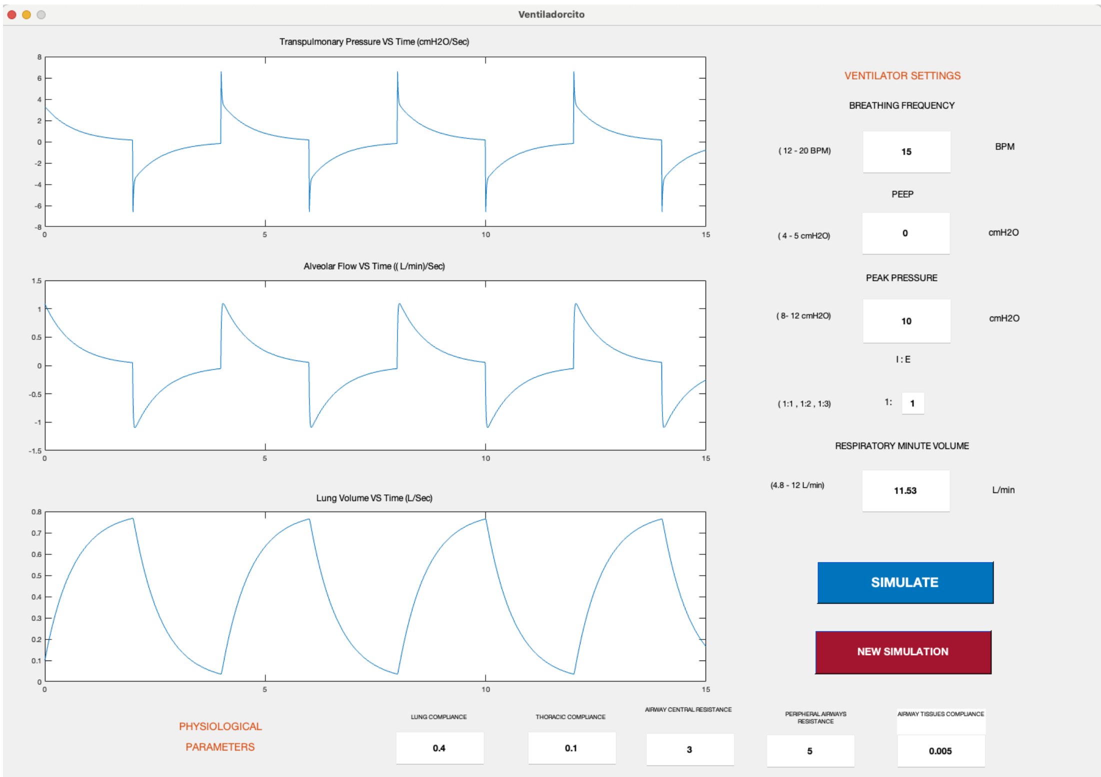

Figure 6: The graphs obtained under restrictive pulmonary disease conditions. **Respiratory minute volume** is recorded as $11.53 L/min$. It has been increased. Furthermore, we can observe that peak lung volume has increased up to $0.8 \ L/sec$.

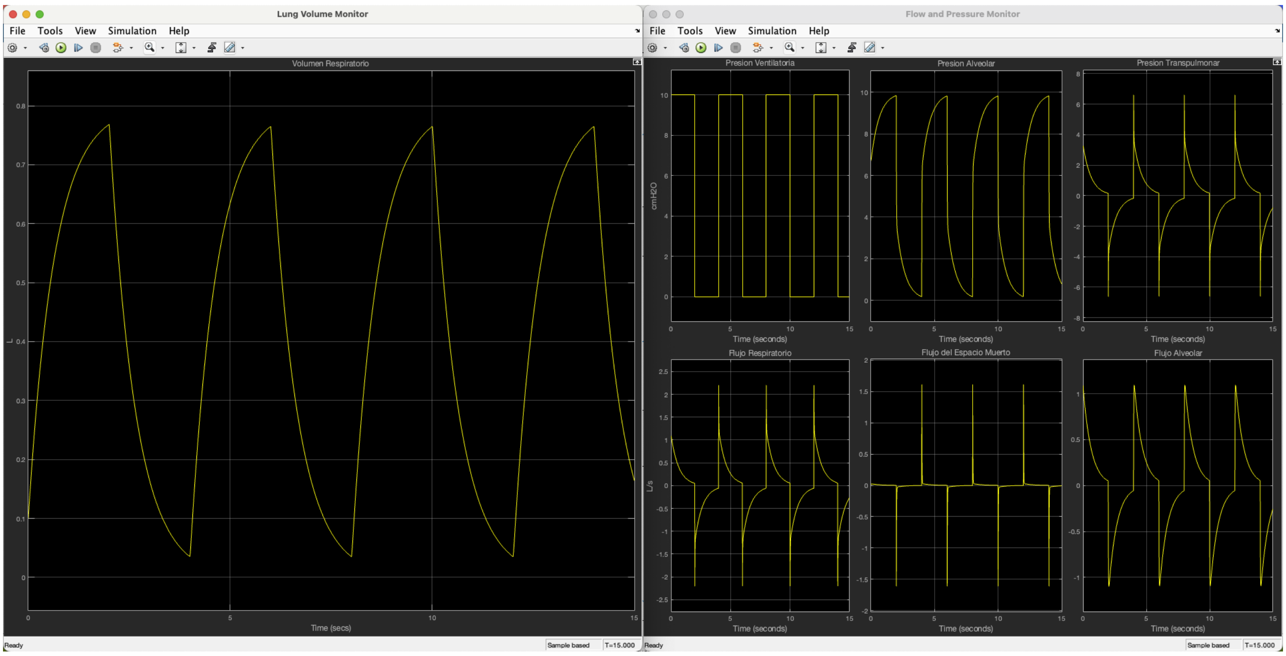

Figure 7: Detailed graphs for lung volume, flow and pressure variables.

6 Comparison of Minute Ventilation

According to [3], Minute ventilation can be defined as follows.

$$Minute\,Venitlation = Respiratory\,rate \times Tidal\,volume$$

However, the GUI automatically calculates and displays the minute ventilation which can be summarized for the three cases as follows.

Normal condition	7.5 L/min
Restrictive pulmonary condition	3.75 L/min
Obstructive pulmonary condition	11.53 L/min

It is clear that during restrictive conditions minute ventilation is decreased. This is because lung volume is reduced. In the other case, obstructive conditions increase resistance during exhalation thus increasing dead space volume and residual volumes per unit time duration. Although it is difficult to breath because of higher resistance, lung volume per unit time is kept higher due to prolonged expiration.

7 References

[1] David Leonardo Rodriguez Sarmiento and Daniela Acevedo Guerrero (2020). Simulation of Respiratory Mechanics on Simulink with GUI `https://www.mathworks.com/matlabcentral/fileexchange/75335-simulation-of-respiratory-mechanics-on-simulink-with-gui`, MATLAB Central File Exchange. Retrieved May 3, 2020.

[2] "#SimulinkChallenge2019: SIMULATION OF RESPIRATORY MECHANICS WITH SIMULINK," www.youtube.com. `https://www.youtube.com/watch?v=b97brGo2Dk0` (accessed Mar. 03, 2024).

[3] S. Hallett, F. Toro, and J. V. Ashurst, "Physiology, Tidal Volume," PubMed, 2021. `https://www.ncbi.nlm.nih.gov/books/NBK482502/`