Project #4 – Modeling pressure dependent lung recruitment

Your task is to program a model of alveolar recruitment and to simulate airway pressure using different inputs.
The use of mathematical models more than ever becomes an integral part of medical decision support. Employing such methods allows predicting a patient's reaction to changes in the therapy strategy. Thus, exploiting those predictions enables finding the optimal therapy to reach a desired outcome in the patient.
The human respiratory mechanics in mechanically ventilated patients can be simulated by a very simple model including a resistance and compliance:

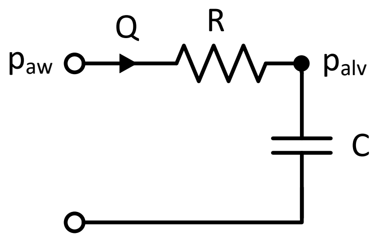


Figure 1: Electrical analogue of the simple first order model of respiratory mechanics.

Here, Q denotes the air flow, R is the airway resistance and C is the static compliance of the lung tissue. p_{aw} and p_{alv} are airway pressure and alveolar pressure, respectively. The model assumes a linear relation between air volume, air flow and airway pressure. In reality however, the relation is non-linear due to multiple reasons. One such reason is that compliance depends on alveolar pressure, e.g. because of re-opening of collapsed alveoli ("recruitment") or over-distension of the lung tissue. The simple model above can be extended to reproduce those effects by replacing the static compliance by a non-linear compliance.

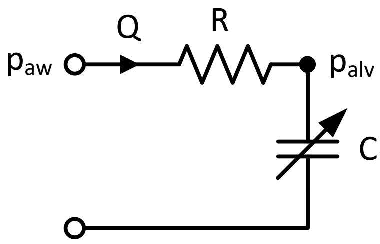


Figure 2: Electrical analogue of the pressure dependent recruitment model (PRM).

The pressure dependent recruitment model (PRM) assumes that the lung is divided in N layers, each being superimposed by a different pressure due to gravity. If the alveolar pressure in one of those layers exceeds the sum of that superimposed pressure (SP) and the threshold opening pressure (TOP), the compliance of that layer is counted towards the total compliance of the lung tissue. At the same time, total compliance decreases with increasing pressure, simulating over-distension. Thus, the behavior of the model can be described mathematically as (Schranz *et al.* 2012):

$$p_{aw} = R \cdot Q + p_{alv} \tag{1}$$

$$\frac{dp_{alv}}{dt} = \frac{1}{\hat{C}} \cdot Q \tag{2}$$

$\hat{C}$ describes the pressure dependent compliance. It is defined as:

$$\hat{C} = C_{FRC} \cdot e^{-K \cdot p_{alv}} + C_L \cdot \sum_{n=1}^{N} H_n \cdot e^{-K \cdot (p_{alv} - SP_n - TOP)} \tag{3}$$

Here, C_{FRC} is the residual compliance, if no layer is recruited; C_L is the compliance of one layer. K is the over-distension factor, while index n denotes the recruitable lung tissue layers. To simulate the pressure dependent opening of a layer, the heaviside function H is used. It is defined as:

$$H = \begin{cases} 0, if\ p_{alv} < (SP_n + TOP) \\ 1, if\ p_{alv} \geq (SP_n + TOP) \end{cases} \tag{4}$$

$$n = 1,2,3,4, \dots, N \tag{5}$$

$$SP_n = 0,0.5,1.0,1.5, \dots \left(\frac{N}{2} - 0.5\right) \tag{6}$$

Task 1

Create a MATLAB function that calculates the compliance $\hat{C}$ for a specific alveolar pressure p_{alv}. The inputs to the function should be (C_{FRC}, K, C_L, SP, TOP, N, p_{alv}). Test your function by calculating the compliance for alveolar pressures from 0mbar to 35mbar (in increments of 0.1mbar). Use the following parameter values (N – total number of lung tissue layers):

Parameter	Value	Unit
TOP	10	mbar
N	30	-
SP	0,0.5,1,...,14.5	mbar
C_{FRC}	45	mL/mbar
K	0.03	1/mbar
C_L	1.7	mL/mbar

Convert the resulting *compliances* $\hat{C}$ into *alveolar volumes* V_{alv} by multiplying them with the *alveolar pressures* p_{alv} you applied. Your result should look like that:

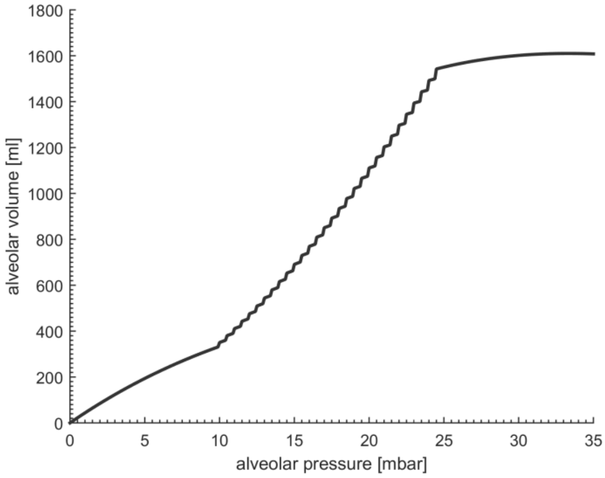


Figure 3: alveolar volume vs. alveolar pressure

You can find the correct results in *Results_Task1.mat*. *C_correct* contains the calculated compliances using *pA_correct* as the alveolar pressure input. *V_correct* is the resulting alveolar volumes.

Task 2

Build the complete model in MATLAB using equation 2 and your compliance function from task 1. Simulate your model with *ode45*, using the parameters from task 1 and a flow Q of 700mL/s. **Do not hardcode** the parameters in your ODE function but pass them as inputs. Simulate for an inspiration time of 2s (increment 0.05s) with $p_{alv}(0) = 0$. Your result should look like this:

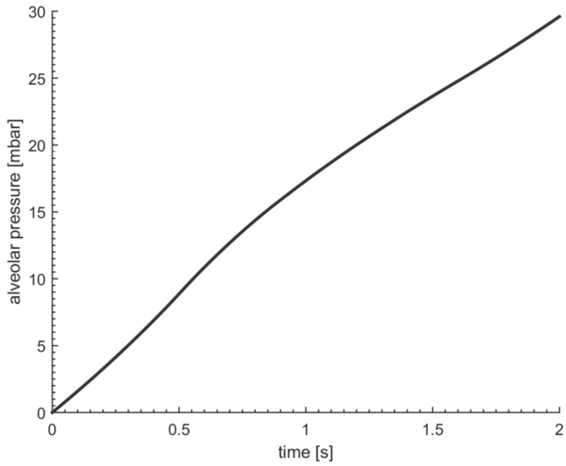


Figure 4: Alveolar pressure over time

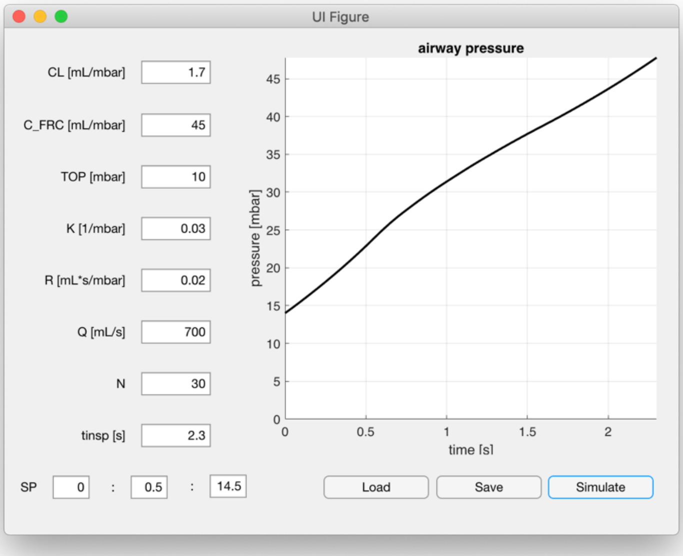
You can also compare your result with *palv_correct* in the file *Results_Task2.mat*.

Task 3

Create a function that calculates airway pressures p_{aw} from the p_{alv} you calculated in task 2 using eq. 1. Apply the same value for Q as in task 2 and use 0.02mbar*s/mL for R. Compare your results with *paw_correct* from *Results_Task3.mat*.

Task 4

Create a GUI to simulate the model. The user should be able to enter parameter values and see the simulation result. Additionally, the user should be able to load patient parameters and save parameters from the GUI to a file. Use the provided patient data file to test loading. Check the file first in MATLAB to see how it is constructed. PRM_ *GUI_ example* contains the GUI below, which you can use to test. Just call it from the MATLAB command window.



To open a file with a file dialog, use:

```
[fileName,pathName] = uigetfile('.mat','Select Patient file');
filePath = fullfile(pathName,fileName);
load(filePath);
```

To save the parameters to a file with a file dialog, use:

```
[fileName,pathName] = uiputfile('.mat','Set filename');
filePath = fullfile(pathName,fileName);
if (length(filePath)>3)
     %here you have to collect all parameter values from the GUI
     %and put them in a structure named "parameters"
     save(filePath,'parameters');
end
```

Try to avoid errors that can be made by the user (start simulation before importing patient file, entering wrong numbers,...) by e.g. disabling buttons or checking entered values.

[1] Schranz, C., Docherty, P. D., Chiew, Y. S., Chase, J. G., and Möller, K. (2012). Structural Identifiability and Practical Applicability of an Alveolar Recruitment Model for ARDS Patients. *IEEE Trans Biomed Eng.*, vol. 59 (12), pp. 3396-404.