Project #5 – Optimization of peak inspiratory pressure

Your task is to identify a model of alveolar recruitment and to optimize the airflow necessary to reach a desired peak inspiratory pressure.
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:

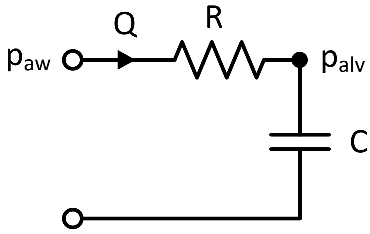


Figure 1: Electrical analogue of the simple first order model of respiratory mechanics.

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.

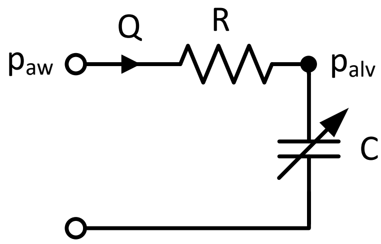


Figure 2: Electrical analogue of the pressure dependent recruitment model (PRM).

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 (Schranz *et al.* 2012).

Task 1

The model is provided in the file *PRM.p*. The signature of that function is:

```
dy = PRM(t,y,TOP,N,Cfrc,K,CL,SP,Q)
```

The model parameters are:

TOP – Threshold opening pressure
N – Number of recruitable lung layers
Cfrc – Residual compliance, i.e. the lung compliance if no lung layer is recruited
K – Overdistention factor simulating loss of compliance at higher pressures
CL – Compliance of one lung layer
SP – Superimposed pressures
Q – input flow

Simulate the model for 2 seconds (increment 0.05s) with *ode45* using the following parameters. The state variable in y is alveolar pressure p_{alv}.

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
Q	700	mL/s

Your result should look like that:

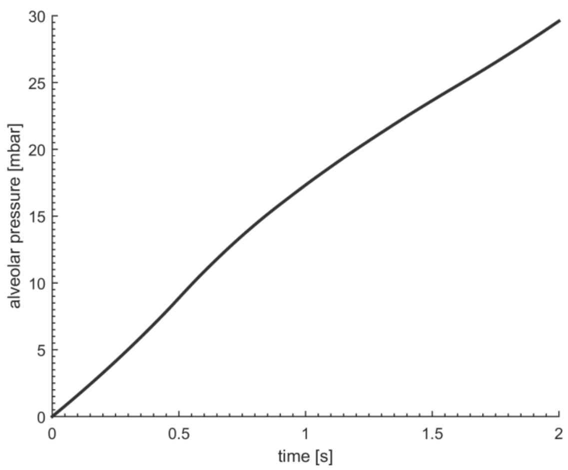


Figure 3: alveolar pressure

You can also compare your result with `palv_correct` in the file `Results_Task1.mat`.

Task 2

The results in task 1 are alveolar pressures p_{alv}. In a clinical context however, airway pressures p_{aw} is the common signal. Therefore, convert the results in task 1 into airway pressures using the following equation:

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

Use R = 0.02mbar*s/mL and compare your result with *paw_correct* from *Results_Task2.mat*.

Task 3

Write the necessary functions to fit your model (parameters TOP, C_{FRC}, K, C_L, R) to data. Test your functions with the measured p_{aw} in `Patientdata_Task3.txt`. Here, a flow of Q = 550 mL/s was applied over a time of 2.5s (measurement frequency = 100Hz).
As initial guess, use the following values:

Parameter	Value	Unit
TOP	12	mbar
C_{FRC}	45	mL/mbar
K	0.03	1/mbar
C_L	1.7	mL/mbar
R	0.02	mbar*s/mL

Your results should be (some are rounded):

Parameter	Value	Unit
TOP	12.11	mbar
C_{FRC}	37.56	mL/mbar
K	0.029	1/mbar
C_L	1.75	mL/mbar
R	0.0244	mbar*s/mL

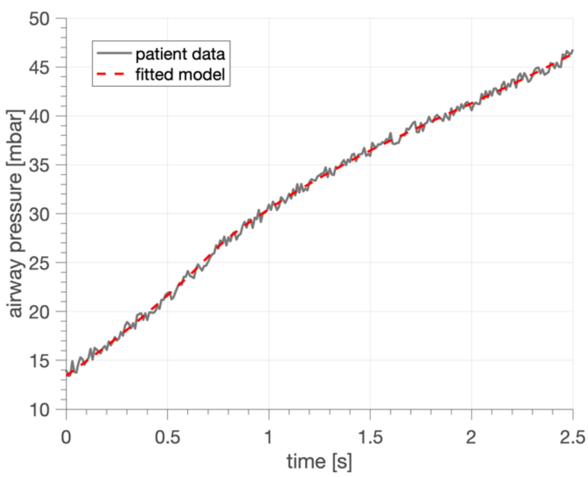


Figure 4: Patient data and fitted model

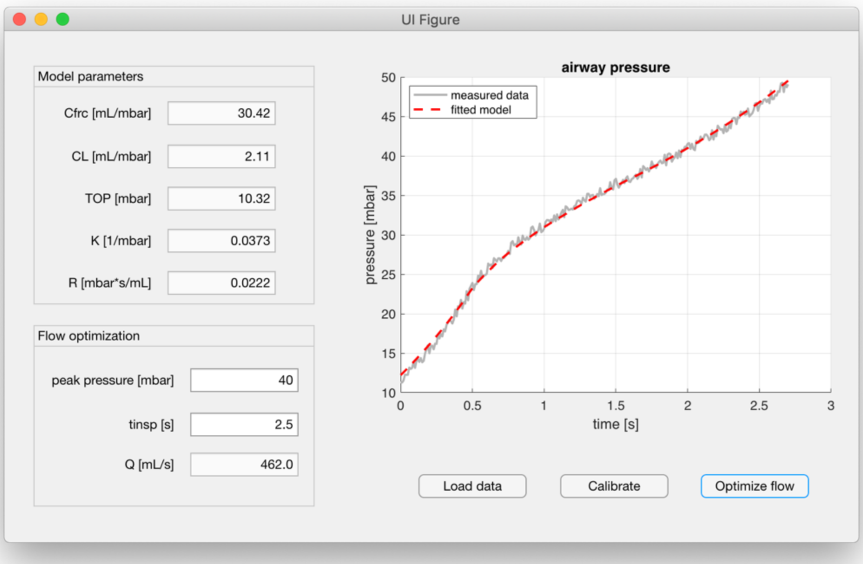
Task 4

Identify the flow that would be necessary to reach a peak pressure of 40mbar. This is basically another parameter identification, where the model parameters are constant and `fminsearch` is used to tune the flow Q. The peak pressure is the last pressure value at the end of the inspiration. Use the identified model above and an inspiration time of 2.5s. Your result should be a flow of $Q = 462.2\text{mL/s}$.

Task 5

Create a GUI to identify the model and to optimize Q to reach a desired peak pressure after a desired inspiration time. Assume a flow of Q = 550 mL/s for the identification, use N and SP from task 1 and the initial guesses from task 3.

GUI_example contains the GUI below, which you can use to test. Just call it from the MATLAB command window. Test your GUI with the two patient files that are provided. Be careful, the inspiration time differs between patients, the measurement frequency however is always 100Hz.



To open a file with a file dialog, use:

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

Try to avoid errors that can be made by the user (start calibration 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.