PROBLEM SET 8

TKT4150 Biomechanics

Main topics: Simulation of wave propagation in compliant pipe with STARFiSh. Reflection factor. Wave splitting. Analysis and visualization in MATLAB.

About STARFiSh

STARFiSh is a freeware Python toolbox, abbreviated from **ST**ochastic **AR**terial **F**low **S**imulations, able to perform calculations of flow in arterial networks. For the interested student, this can be downloaded to run simulations on your own using Python. In this problem set, however, the results from such simulations are simply given.

(1) Wave splitting

The pressure and flow in a compliant vessel can be split into contributions from forward and backward propagating waves, as follows:

$$p = p_f + p_b \tag{1}$$
$$Q = Q_f + Q_b \tag{2}$$

Furthermore, the characteristic impedance is defined[1]*:*

$$Z_c \equiv \frac{p_f}{Q_f} = -\frac{p_b}{Q_b} \tag{3}$$

a) Based on Equations 1 - 3, show that the expressions for the pressure and flow of the forward and backward propagating waves can be written:

$$p_f = \frac{p + Z_c Q}{2} \qquad p_b = \frac{p - Z_c Q}{2} \tag{4}$$
$$Q_f = \frac{Q + p/Z_c}{2} \qquad Q_b = \frac{Q - p/Z_c}{2} \tag{5}$$

[1] It is assumed that the pressure used is expressed relative to the diastolic; i.e. as the difference between the systolic and diastolic pressure

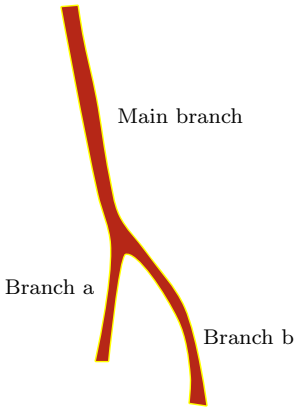

Figure 1: *Bifurcation of artery.*

(2) Reflection from bifurcation

Assume that we have an artery that bifurcates, as illustrated in Figure 1. The change in the artery at the bifurcation results in a reflection of the original wave. Figure 2 shows the pressure and volume flow in the aorta based on the bifurcation system estimated by STARFiSh, when the period of the incoming pulse is T=0.2s. Figure 3 shows the same results from the bifurcation, when it is exposed to an incoming pulse with period T=0.5s.

a) Propose an estimate of the reflection factor that this bifurcation results in, based on this plot.

b) As seen in Figure 3, the estimation of an reflection factor is not as straightforward when the pulse period increases; the forward going and reflected waves are mixed more together. Perform a wave split calculation, using the data found in 'ex10_bifurcation.mat', to estimate the reflection factor. Present the resulting plot as well.

(3) Wave splitting from simulated flow and pressure in arterial network

The arterial network of a human being is illustrated in Figure 4. STARFiSh is used to run a simulation of a model of the complete arterial network, to yield time series of pressure, flow, wave speed and compliance. This is performed for two different models; one representing a 19 year old test subject and one representing a 75 year old test subject, with results found in the files 'ex10_age19.mat' and 'ex10_age75.mat', respectively.

a) Calculate the pressures for the forward and backward propagating waves. Present the results in plots containing the time series of p, p_f and p_b, one for each of the two test subjects.

b) How does age influence the reflected (backward) pressure wave?

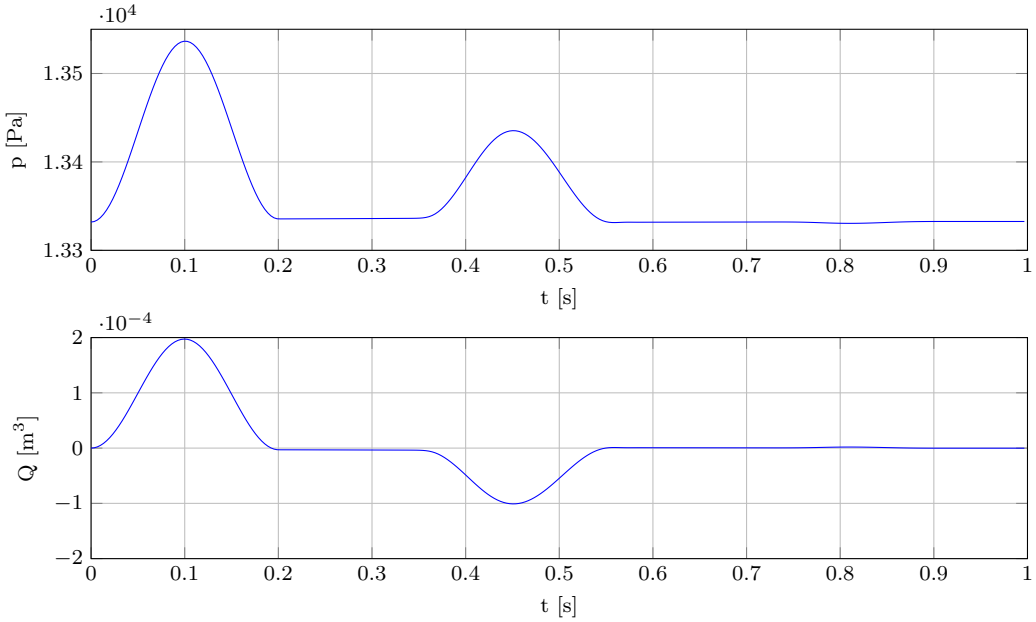

Figure 2: *Pressure and flow in aorta for T=0.2s.*

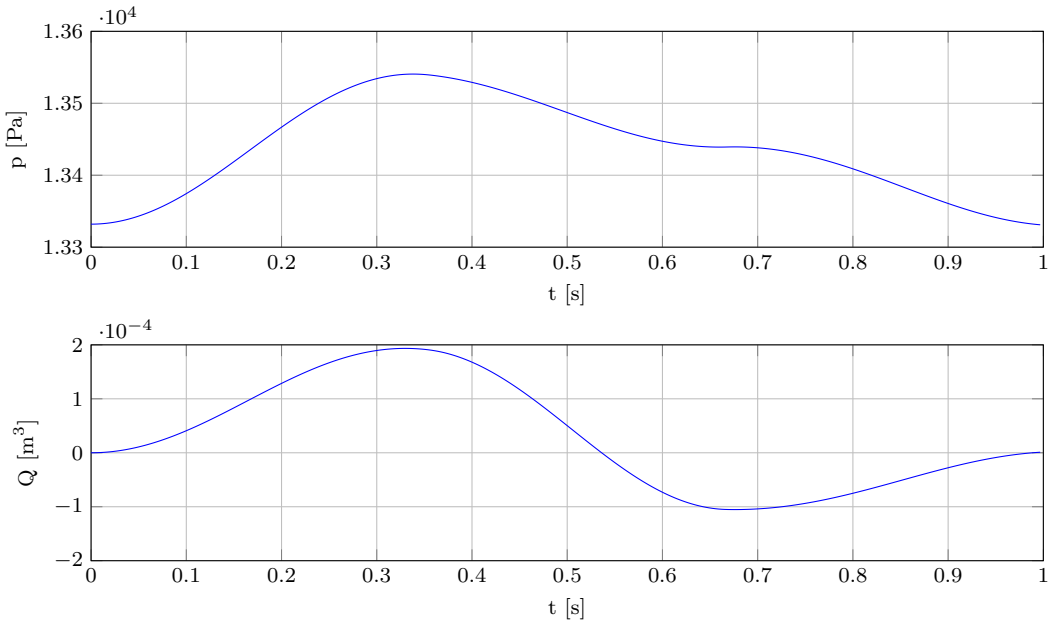

Figure 3: *Pressure and flow in aorta for T=0.5s.*

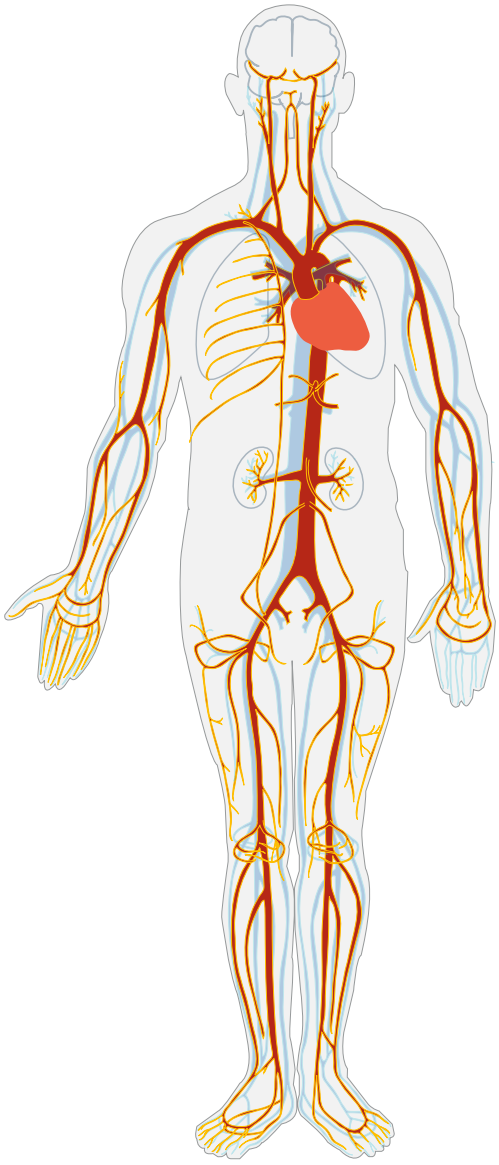

Figure 4: *Arterial network of human being. Figure is based on "Arterial System en" by LadyofHats, Mariana Ruiz Villarreal - Licensed under Public domain via Wikimedia Commons.*