Arterial Blood Flow Model: Test Cases

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1 Macrovasculature Blood Flow Model

All simulations use a reflective boundary condition where outflow is defined by a reflective coefficient R_t,

$$W_b = -W_f R_t. \tag{1}$$

where, $0 \leq R_t \leq 1$ and $W_{f,b}$ are the forward and backward propagating characteristics.

Table 1 houses the fluid properties, which remain the same for all of the following test cases. Likewise, certain vessel wall properties also remain constant — also found in Table 1. Those that do vary between test cases will be stated within the corresponding section.

Table 1: Properties of the fluid and vessel wall.

Parameter	Value
Fluid	
Transport Model	Newtonian
Density, ρ	1060 kgm^{-3}
Dynamic Viscosity, μ	0.004 Pa s
External Pressure, p_e	0 Pa
Profile Coefficient, γ	9
Vessel Wall	
Young's Modulus, E_0	$400,000$ MPa
Wall Thickness, h_0	0.0015 m
Poisson's Ratio, nu	0.5
Length, L	0.4 m

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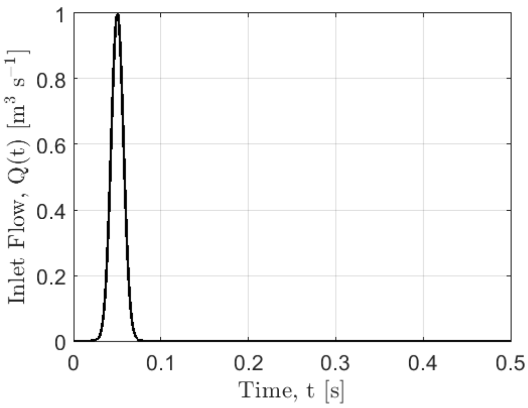

Figure 1: Inlet flow over time as used for all but the last test case.

The initial condition for all cases is such that flow velocity is 0. The initial area is equal to A_0 — provided in each section. The time-varying inlet is the same for all but the last test case. It takes the form of a Gaussian wave of the form,

$$Q(t) = \left(5 \times 10^{-5}\right) \exp\left[-\left(\frac{0.05 - t}{0.01}\right)^2\right] \tag{2}$$

and represents the blood flow (m^3 s^{-1}) entering the vessel. This is applied by considering the wave characteristics, allowing for the representation of this condition in terms of $A(0,t)$ and $u(0,t)$. Figure 1 shows the time-evolution of this condition.

1.1 Gaussian Wave in a Continuous Artery

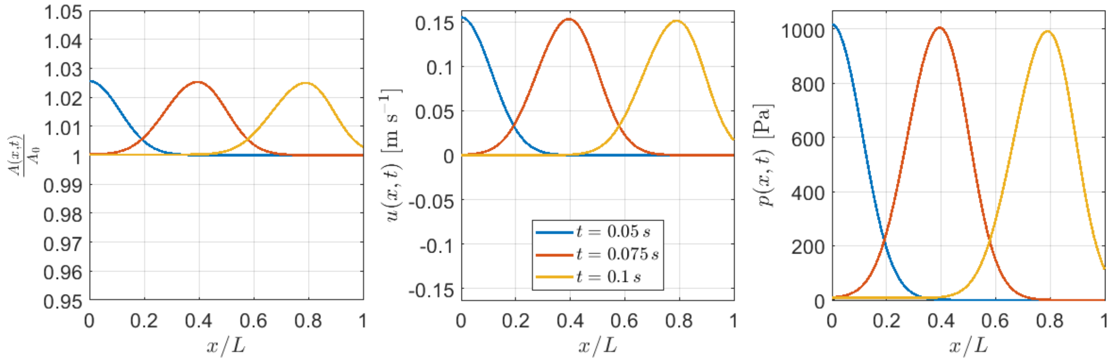

Figure 2: Three time steps presenting the change in area, velocity, and pressure across the vessel's length for the continuous case. $r_p = r_d = 0.01$ m, $R_t = 0$.

1.2 Gaussian Wave in an Expanding Artery

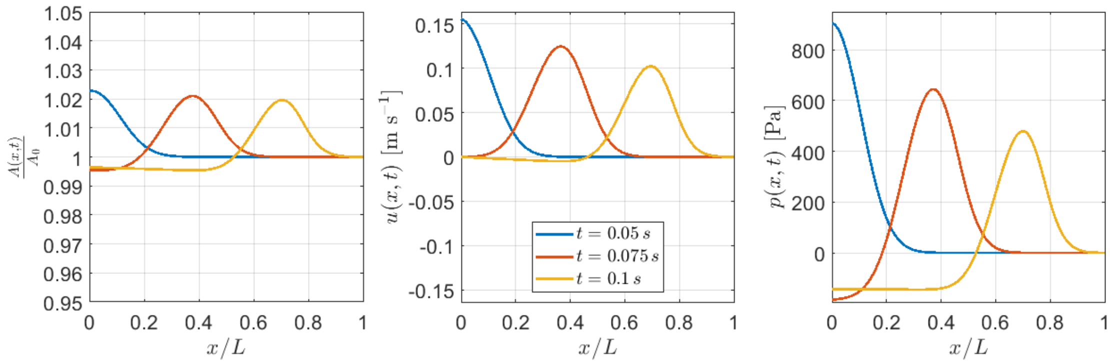

Figure 3: Three time steps presenting the change in area, velocity, and pressure across the vessel's length for the expanding case. $r_p = 0.01$ m, $r_d = 0.02$ m, $R_t = 0$.

1.3 Gaussian Wave in a Tapered Artery

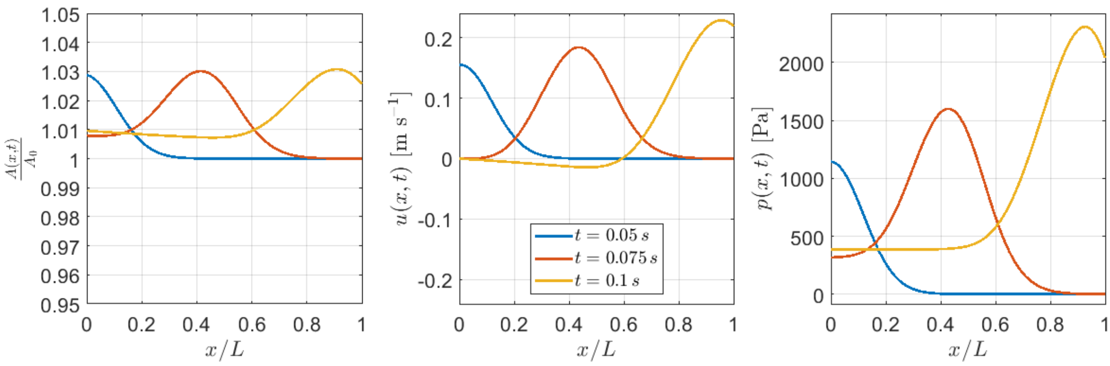

Figure 4: Three time steps presenting the change in area, velocity, and pressure across the vessel's length for the tapered case. $r_p = 0.01$ m, $r_d = 0.005$ m, $R_t = 0$.

1.4 Gaussian Wave in a Partially Narrowed Artery

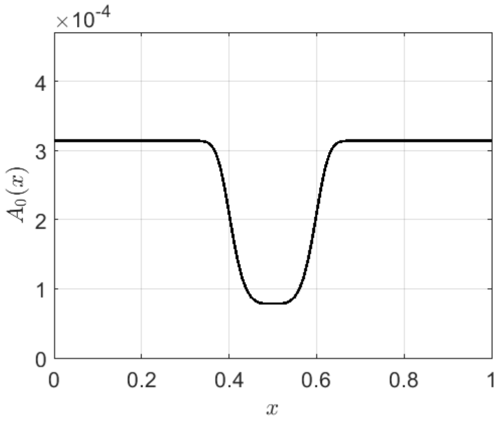

Figure 5: A_0 as function of x for the partially stiffened case. $r_{0,max} = 0.01$ m, $r_{0,min} = 0.005$ m, $c = 1.0$, $x_0 = 0.2$ m.

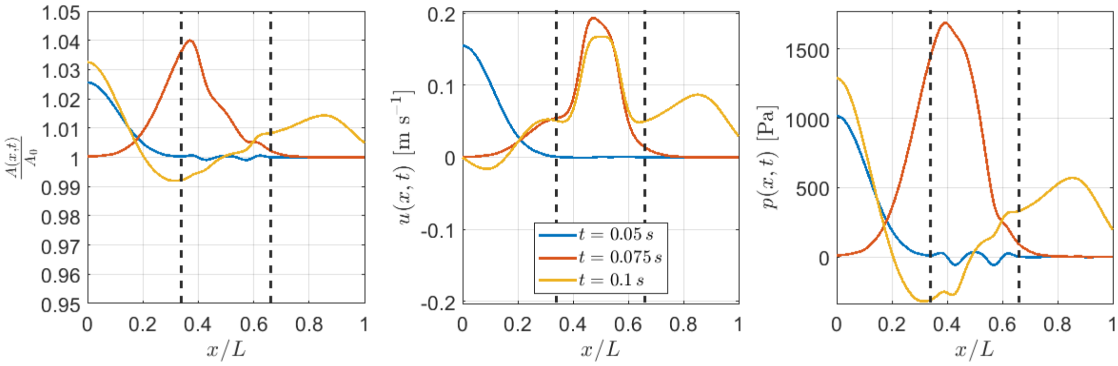

Figure 6: Three time steps presenting the change in area, velocity, and pressure across the vessel's length for the partially narrowed case. See Figure 5 for $A_0(x)$ function.

1.5 Gaussian Wave in a Partially Stiffened Artery

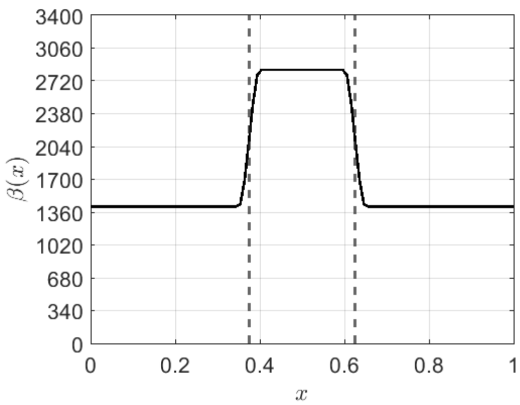

Figure 7: β as function of x for the partially stiffened case. $\kappa = 2$, $\delta = 0.01$, $a_1 = 0.15$ m, $a_2 = 0.25$ m.

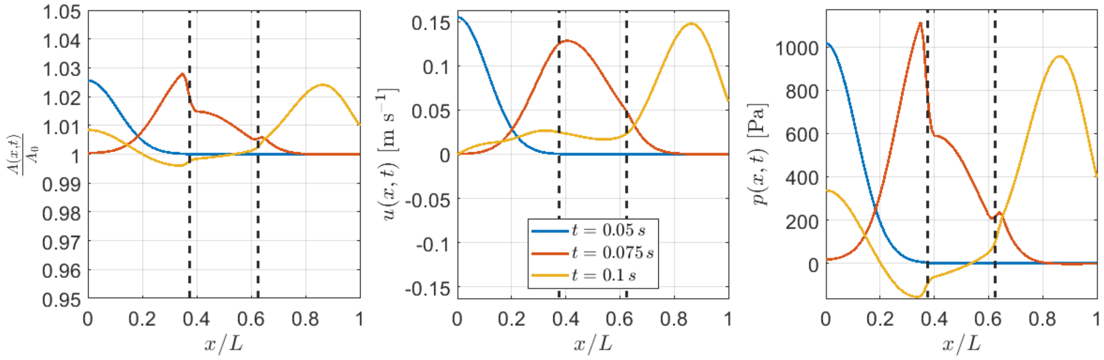

Figure 8: Three time steps presenting the change in area, velocity, and pressure across the vessel's length for the partially stiffened case. $r_p = 0.01$ m, $r_d = 0.02$ m, $R_t = 0$. See Figure 7 for $\beta(x)$ function.

1.6 Gaussian Wave in a Stenotic Artery

The stenotic test case uses the same x-dependent functions for variable area and stiffness as the partially narrowed and stiffened cases. However, here $\kappa = 5$ instead of $\kappa = 2$ as used in the stiffened test case.

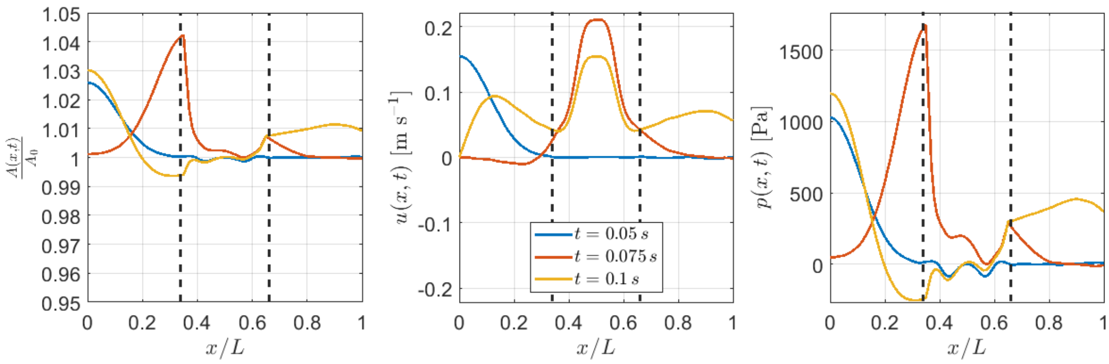

Figure 9: Three time steps presenting the change in area, velocity, and pressure across the vessel's length for the stenotic case. See text for case details.

1.7 Gaussian Wave in a Singly Splitting Arterial Network

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1.8 Gaussian Wave in a Singly Merging Arterial Network

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1.9 Heartbeat Cycle in a Full Arterial Network

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2 Skeletal Muscle Oxygenation Model

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3 Microvasculature Flow Model

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4 Microvasculature Dilation Model

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