Thesis proposal

Metode računalne dinamike fluida se, zadnjih godina, često primjenjuju kod proučavanja hemodinamike strujanja u krvožilnom sustavu. Od posebnog interesa je strujanje kroz stenotične arterije, to jest arterije s naglim suženjem poprečnog presjeka, koje obično nastaje radi nakupljanja plaka. Kod modeliranja strujanja kroz stenotične arterije vrlo često se pretpostavlja da se krv ponaša kao Newtonski fluid, odnosno da postoji linearna veza između gradijenta brzine strujanja i smičnog naprezanja, iako to nije u potpunosti točno. Dokazano je da se viskoznost krvi smanjuje s povećanjem smičnog naprezanja (eng. *shear-thinning*). Također su primiječena određena viskoelastična svojstva krvi, primarno, postojanje graničnog smičnog naprezanja prije kojeg se ne ostvaruje tok. S obzirom da odabir modela fluida može bitno utjecati na strujanje, potrebno je usporediti razlike između modela kako bi se mogla provesti adekvatna hemodinamička analiza stenotičnih arterija.

Cilj ovog rada je napraviti numeričku analizu strujanja kroz idealiziranu stenotičnu arteriju koristeći različite reološke modele krvi te usporediti strujne karakteristike dobivene korištenjem istih. Uz pretpostavku laminarnog, izotermnog strujanja nestlačivog fluida potrebno je usporediti utjecaj tri različita reološka modela krvi:

- Newtonski
- generalizirani Newtonski
- viskoelastični

Potrebno je odrediti utjecaje reoloških modela za slučaj stacionarog i oscilatornog strujanja. Rezultate je potrebno usporediti s onima dostupnima u literaturi, gdje god je to moguće.

U radu je potrebno navesti korištenu literaturu i eventualno dobivenu pomoć.

Pitanja/komentari:

- nisam spomenuo da ima više geometrija stenoze (3)
- nisam spomenuo da hoćemo usporedit osnosimetrični i full-3D slučaj
- nisam spominjao različite Reynoldsove brojeve (50 i 200, 1 mi se čini bezveze)
- nisam rekao ništa o foamu/softwareu

Thesis outline

General

Items to be provided:

- computational meshes (2D axisymmetric slice and 3D)
- comparison data, extracted from relevant literature [1] (see also [2, 4, 8])
- viscoelastic solver, modified version of the one used in [1] (see [3, 5] for theory), and any additionally required boundary conditions
- basic case templates

Parameter values, expressions and the like:

- assume laminar flow of an incompressible fluid
- stenosis geometry definition, as per [1, 8]:

$$\frac{r}{R_0} = 1 - \frac{a}{2R_0}\left[1 + \cos\left(\frac{\pi z}{b}\right)\right] - b, \quad -b \leq z \leq b$$

- parameter definitions:

a	m	stenosis height
b	m	stenosis half-length
D	m	unobstructed pipe diameter
$\overline{p} = pR_0/(\mu U_{\text{ref}})$		dimensionless pressure, as per [2]
R_0	m	unobstructed pipe radius
$Re = \rho U_{\text{ref}} D/\mu$		Reynolds number, as per [1]
r	m	radial coordinate
$\boldsymbol{U}$	$\text{m}\,\text{s}^{-1}$	flow velocity
U_{ref}	$\text{m}\,\text{s}^{-1}$	mean flow velocity in unobstructed pipe
z	m	axial coordinate

- tracked values:
  - radial velocity profile at $z = 0$
  - dimensionless pressure drop ($\Delta\overline{p} = (p_{\text{in}} - p)/(\rho U_{\text{ref}}^2)$, as per [8]) along pipe axis
  - dimensionless pressure drop ($\Delta\overline{p} = (p|_{z=-16R} - p|_{z=+16R})/(\rho U_{\text{ref}}^2)$) along the axis
  - dimensionless forces acting on the stenosis wall (assuming $\overline{F} = F/(R^2\pi\rho U_{\text{ref}}^2)$)

Thesis progression

1. Perform mesh independence study for the 2D and 3D cases using the following setup:

   - steady state flow for $Re = 200$
   - M2 geometry (see [1, 8])
   - viscoelastic transport model — multi-mode sPPT model (see [6]), using model parameters from [1]

   — to be provided

2. Perform a parametric study for the steady state 2D axisymmetric case:

   - include M0–2 geometries (see [1, 8])
   - perform simulations for $Re \in \{50, 200\}$
   - using data from [1] for model parameter fitting, include three different transport models for blood:
     - Newtonian ($\mu =$ const.)
     - generalized Newtonian (Carreau-Yasuda)
     - viscoelastic (multi-mode sPTT, see [6])

   Compare results with provided data, extracted from [1].

3. Perform a parametric study for the oscillatory flow in the 2D axisymmetric and 3D cases:

   - include M0–2 geometries (see [1, 8])
   - perform simulations at $Re \in \{50, 200\}$
   - using data from [7] for model parameter fitting (sPTT model parameters taken directly from [1]), include three different transport models for blood:
     - Newtonian ($\mu =$ const.)
     - generalized Newtonian (Carreau-Yasuda)
     - viscoelastic (multi-mode sPTT, see [6])

   Compare 2D and 3D results with provided data, extracted from [1].

TODO

1. define how mesh independence will be determined — done
2. extract and provide comparison data from [1] — done
3. define values to be monitored (sections, probe locations, graphs, etc.) — done
4. define flow rate variation for the transient cases — done
5. fit Carreau-Yasuda model parameters to data from [7] — done
6. add relevant literature for Carreau-Yasuda model (and stuff proving common use in hemodynamics)

Literature

[1] A. Chauhan i C. Sasmal. Effect of real and whole blood rheology on flow through an axisymmetric stenosed artery. *International Journal of Engineering Science*, 169:103565, 2021. ISSN: 0020-7225. DOI: 10.1016/j.ijengsci.2021.103565.

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