Assessing The Impact of Dynamic Mesh Approach within a Heart Pump Using STAR-CCM+

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Overview

- Background about the ventricle assist device
- Computational model of pulsatile LVAD design
- Modelling of the valves and pusher plate moving
- Computational model of continuous blood pump design
- Results and discussion
The Human Heart and the heart as a pump

- Two upper chambers; **atria** (transferring)
- Two lower chambers; **ventricles** (pumping)
- Four valves

- Two types of heart assist device:
  - Total artificial hearts (TAHs)
  - Ventricular assist devices (VADs): LVAD or RVAD

50cc Penn State (LVAD) (V2 design)
According to the development of VADs, we can rate the VADs into three generation as shown below:

- **1st generation**: *pulsatile pump*
- **2nd and 3rd generation**: *Rotary continuous flow*
All the simulations were solved via STAR-CCM+® v10.02 to solve the conservation of mass and momentum equations.

The meshes were created for the 3-D simulations using both Pointwise and STAR-CCM+.

An overcast mesh algorithm is used for each instance of mesh motion, and a zero-gap technique was employed to ensure full valve closure.
The Elliptic Blending Reynolds Stress Model (EB-RSM) is used here to capture the effects of turbulence.

Two common models for Non-Newtonian blood flow (Carreau and Cross) are compared to the Newtonian model to investigate their impact on predicted levels of shear rate and wall shear stress.

Spatial resolution
- Five different meshes were created.
- The mesh M4 (2,541,665) is selected for the following simulation.

The forth cycle has been chosen to extract the data from the simulation.
Results and discussion

Comparison of mean flow field

- The current numerical simulations are validated against the instantaneous flow fields from the *in-vitro* tests of the same device. The comparisons consist of traces of instantaneous velocity magnitude at extraction points in the chamber for all models.
Examination of non-Newtonian blood rheologies

- The valve position in the inlet and outlet ports gives rise to **complexity of the flow behaviour inside the chamber** throughout the cycle.
- For the **sake of clarity** the streamlines in the figure are divided into two groups (1st group: lines 1 and 2, 2nd group: lines 3 and 4) at \( t/T = 0.3 \).
- It can be observed that the **re-circulation regions are enlarged in the non-Newtonian models**, especially in the cross model (see lines 2 and 4). This observation is significant in implying that the **identification of regions of flow stagnation**.
Sensitivity of x-velocity profile of lines within the domain

Diastolic phase

Systolic phase
Clinical issues of shear stress

- Potential blood clot damage models concerning shear stress and exposure time.
- Flow patterns that contribute to the haemolysis potential include areas of raised shear stress around the valves, which contribute to platelet activation.
- This was investigated by plotting contours of viscous shear stress at three planes as shown in the figure for Newtonian model.
The figure illustrates contour of wall shear stress (WSS).

Results are displayed for the Newtonian and Carreau models. Snapshots of WSS are plotted over the surface of the chamber and the mitral zone at early/peak of diastolic phase and over the aortic zone and chamber at peak/late of systole. From the figure, it can be seen that the differences between the models are relatively low, particularly in the mitral and aortic zones.
The centrifugal blood pump proposed by FDA (Food and Drug Administration) (CBP-FDA) is a simple centrifugal type, which is composed of impeller (rotor), pump housing, inlet and outlet tube as shown in the figure.
Meshes were built with **Pointwise** (V16.04R4) and **STAR-CCM+** (V10.02), as shown in the figure.

From this figure, it can be observed that the mesh of **inlet and outlet** ports are created using **structured mesh** by **Pointwise** and **Polyhedral mesh** for **other parts** of the pump using **STAR-CCM+**.
The multiple-reference frame (MRF) approach or steady-state moving reference model must be used to study the behaviour of blood flow as steady-state simulation within the CBP-FDA.

The sliding mesh technique or transient rigid body motion model for unsteady.

3-D, turbulent flow using EB-RSM model.

Six different cases were employed to operate the CBP-FDA.

Five different meshes were used to investigate the spatial mesh required.

<table>
<thead>
<tr>
<th>Simulation cases</th>
<th>Volume Flow Rate (L/min)</th>
<th>Pump speed (RPM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>2.5</td>
<td>2500</td>
</tr>
<tr>
<td>Case 2</td>
<td>2.5</td>
<td>3500</td>
</tr>
<tr>
<td>Case 3</td>
<td>4.5</td>
<td>3500</td>
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<tr>
<td>Case 4</td>
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<td>2500</td>
</tr>
<tr>
<td>Case 5</td>
<td>6.0</td>
<td>3500</td>
</tr>
<tr>
<td>Case 6</td>
<td>7.0</td>
<td>3500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mesh</th>
<th>MC1</th>
<th>MC2</th>
<th>MC3</th>
<th>MC4</th>
<th>MC5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mesh cells</td>
<td>794,490</td>
<td>1,758,441</td>
<td>3,699,425</td>
<td>5,691,749</td>
<td>7,554,649</td>
</tr>
</tbody>
</table>
Results

Velocity magnitude within the blade passage and outlet

Case 1
Case 2
Case 3
Case 4
Case 5
Case 6

Velocity magnitude (m/s)

0.00  0.44  0.89  1.33  1.78  2.22  2.67  3.11  3.56  4.00  4.44  4.89  5.33  5.78  6.22  6.67  7.11  7.56  8.00
Shear rate to investigate the non-Newtonian effect

Case 1
Case 2
Case 3
Case 4
Case 5
Case 6

Shear rate (1/s)

0.00  28  56  83  111  139  167  194  222  250  278  306  333  361  389  417  444  472  500


Thanks for your listening

Questions ??