HIGH-FIDELITY TURBULENCE MODELLING OF THE NEOVAD PAEDIATRIC PUMP

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Introduction

Around 0.8% of babies born alive have chronic heart failure [1]. The NeoVAD is a prototype left ventricular axial flow pump for neonates to support left ventricular failure. Current work has investigated the optimal blade design of the impeller in this pump using machine learning and global optimization [2]. However, this device is expected to operate in the transitional and turbulent flow regimes, with the implication that turbulent stresses contribute to mechanical blood trauma [3]; higher fidelity computational fluid dynamics (CFD) simulations are needed to model the flow fields. Building on the existing numerical work, this work aimed to use high-fidelity Large Eddy Simulations (LES) to calculate the flow fields found in the NeoVAD pump.

Methods

CFD simulations of the flow through the NeoVAD pump were investigated using OpenFOAM v9. The flow (Q) was simulated from 0.5 - 4 l/min with a constant impeller speed, equivalent to an impeller tip Re = 32,000. To investigate the effects of the turbulence model on pressure head (H) Unsteady Reynolds Averaging Navier-Stokes (URANS) and LES were used. For turbulence closure the k-ω SST model was chosen for URANS, and the Wall Adapting Local Eddy-viscosity (WALE) model was chosen for LES. URANS models were performed using both a multiple reference frame (MRF) and a sliding mesh approach, with the MRF models used to initialize the transient solutions. Numerical models are compared to experimental pressure measurements from rapid prototyped parts.

Results

CFD simulations using the $k - \omega$ SST model found a slightly lower pressure when compared to the WALE model at all flow rates, Figure 1. At 0.5 l/min, both turbulence models produced pressures similar to experiments. At 2 l/min there was 13.5% absolute difference between the WALE model and experiments.

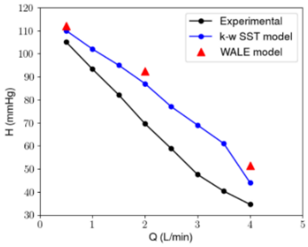

Figure 1: HQ curve for k-ω SST, WALE simulations and experiments.

A qualitative assessment of the flow fields between turbulence models at 2 l/min (Figure 2a and 2b) showed obvious unsteadiness downstream of the diffuser section in the the WALE compared to $k - \omega$ SST model.

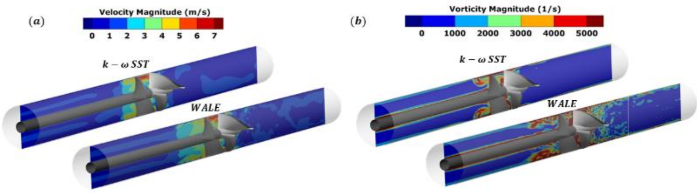

Figure 2: $k - \omega$ SST and WALE CFD simulations of the NeoVAD at 2 l/min. (a) velocity fields (b) vorticity fields.

Discussion

HQ curves between URANS and LES models showed similar trends at the respective flow rates. Although both turbulence models overpredicted the pressure head we expect the 3D-printed geometries to have surface roughness resulting in underpredicting the correct pressures [4]. The effect of surface roughness is currently under investigation.

These preliminary simulations of LES models indicate that the flow fields are complex at the operating point of interest for paediatrics and URANS is not capable of capturing the turbulent structures that could potentially lead to mechanically induced blood damage.

Future work will include the determination of turbulent shear stresses from URANS and LES models to quantify mechanical blood trauma and include surface roughness in the models.

References

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Acknowledgements

Research supported by the National Heart, Lung, and Blood Institute of the National Institute of Health under Award Number 1R01HL153538-04. This work used the Isambard 2 UK National Tier-2 HPC Service (http://gw4.ac.uk/isambard/) operated by GW4 and the UK Met Office, and funded by EPSRC (EP/T022078/1)