

## Effect of Induced Vibration on the Blood Flow Properties in a Mechanical Aortic Valve

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**Abstract.** The effect of induced vibration on velocity distribution for the blood flow in the bileaflet mechanical heart valves conveying blood was investigated in this study. The bileaflet valve was simulated as an orifice. The induced vibration is due to the pulsed blood flow in the artery. Results presented in this study were performed using CFD FLUENT software. This analysis is based on the non-linear numerical solution by using a finite-element method, for the system of governing partial differential equations (continuity, momentum) of Navier - Stokes equation of blood flow through the orifice. It has been found that as the flow through the orifice increased, the vibration at the orifice inlet increased. For steady state conditions, at Reynolds number 50 the recorded frequency was 20Hz. When the Reynolds number increased to 100 due to the increase in the blood flow the recorded frequency increased to 30Hz. The increase in frequency may result in damaging the blood red cells and platelets which subsequently results in increasing the blood clogging downstream of the orifice.

### 1 Introduction

The human heart is a biological pump that moves blood throughout the human body through the circulatory system. The proper function of human heart is essential for human life. The heart is composed of four compartments (two atria and two ventricles) and these connected with two heart valves. Heart valve disease, including valvular stenosis, palaces (failure in aortic valve), may occur in the valve leading to the need for valve replacement. It has been found that 95% of patients using artificial heart valves exhibits failure in aortic valve and thus requires replacement of the coronary and aortic valves [1]. There are two types of artificial heart valves (prosthetic valve) which are mechanical prostheses, and biological valves. Mechanical prostheses valve has solid, manufactured occluders; however, the biological valve is made of tissues and has flexible occluders of animal or human origin. [2]. In this research the effects of Reynolds number and inlet velocity profile which is causes induced vibration due to blood flow circulation (Coriolis force) on the valve leaflet deflection are investigated by using computational fluid dynamics together with static structure modeling techniques. The variation of deflection that may occur at the valve leaflet due to change in blood flow is presented. This deflection may result in valve failure.

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Continuity equation:

$$\left(\frac{\partial u}{\partial x}\right) + \left(\frac{\partial v}{\partial y}\right) = 0 \quad (3)$$

Momentum equation in x- direction:

$$\left[u\left(\frac{\partial u}{\partial x}\right)\right] + \left[v\left(\frac{\partial u}{\partial y}\right)\right] = -\left[\left(\frac{1}{\rho}\right) * \left[\left(\frac{\partial p}{\partial x}\right)\right] + \nu * \left[\left(\frac{\partial^2 u}{\partial x^2}\right) + \left[\left(\frac{\partial^2 u}{\partial y^2}\right)\right]\right] \quad (4)$$

Momentum equation in y- direction:

$$\left[u\left(\frac{\partial v}{\partial x}\right)\right] + \left[v\left(\frac{\partial v}{\partial y}\right)\right] = -\left[\left(\frac{1}{\rho}\right) * \left[\left(\frac{\partial p}{\partial y}\right)\right] + \nu * \left[\left(\frac{\partial^2 v}{\partial x^2}\right) + \left[\left(\frac{\partial^2 v}{\partial y^2}\right)\right]\right] \quad (5)$$

Figs 1 and 2 show the dimensions of the aortic valve and the artery [3, and 4]. The maximum opening angle of the valve under the start conditions prior to the systole is 10°. However, during the diastole conditions the maximum angle of the valve is 85° (Table 1). In This research, the induced vibration occurred at 75° leaflet angle (full peak systole) is investigated.

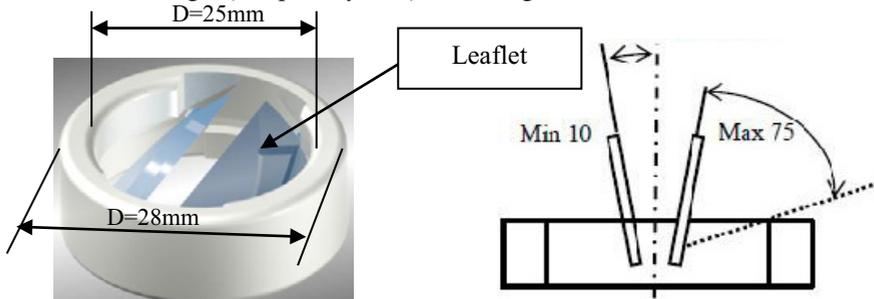


Figure 2. Model of the bileaflet aortic valve prototype

Table 1 Material property [5].

Material	Density(Kg m <sup>-3</sup> )	Young's Modulus (MPa)	Poisson's ratio
Aortic wall	2000	6	0.4
Plaque (Fibrosis)	-	1	0.01
Bi-leaflet valve housing(Titanium)	4500	120	0.33
Bi-leaflet valve ring and leaflets (pyrolytic carbon)	1500	20	0.3

For patients with artificial valve implant in their heart, the blood velocity enters the artery is 7 cm/s [6]. Furthermore, the maximum pressure to support in the ventricle during the closing mechanical of aortic valve is 120 mmHg [5]. Most artificial valves are made of titanium alloy (Ti 6Al4V), graphite, pyrolytic carbon, and polyester. The titanium is used for the housing or outer ring, graphite coated with pyrolytic carbon is used for the bileaflet, and 100% pyrolytic carbon impregnated with tungsten is used for the inner ring [5].

### 3.2 Model development and boundary conditions

The following boundary conditions have been considered in this study

- 1- No slip conditions at the walls.
- 2- Steady state simulation
- 3- Fixed to support in tow end is used in the FSI model.
- 4- Blood temperature 37°C.

The number of elements used in the model is 3127602 (Fig. 3). A mesh independence study has been performed and found that increasing the number of elements beyond 3127602 will not change the results. The cells skewness was found to be 0.7 which considered acceptable.

As mentioned that fluid-structure interaction (FSI), technique is used to model the blood flow and to study the subsequent vibration generated in the aortic valve. FSI is able to model the fundamental interaction between the fluid and the valve leaflets.

### 4 Results and discussion

Fig. 4 shows the velocity distribution contours; as expected for Reynolds number 50 the downstream blood velocity magnitude was less than the velocity magnitude at Reynolds number 100. However, the highest velocity magnitude downstream of the valve is recorded at Re 150. From the FSI model, the resultant induced vibration for the above Reynolds numbers was 20 Hz at Reynolds equal to 50. For Reynolds number of 150 it is found that the induced frequency has been increased to 30 Hz.

The pressure distribution contours in the flow field (Fig. 5) show that as the Reynolds number increased from 50 to 150, an increase in the adverse pressure of 11% is recorded at downstream of the aortic valve. From FSI results (Fig. 6) it has been found that resultant deflection due to the induced vibration at the bilefflet has increased from 0.0074 mm at Reynolds 50 to 0.0168 mm at Reynolds 150. This is attributed to the increase in the vibration (increase from 20Hz at Reynolds 50 to 30Hz at Reynolds 150). As shown in the figures below that the increasing of the Reynolds number for the fluid caused an increase in the vibratory amplitudes due to the increase in the blood flow velocity which resulted in increasing the amount of blood flow rotating force (Coriolis force).

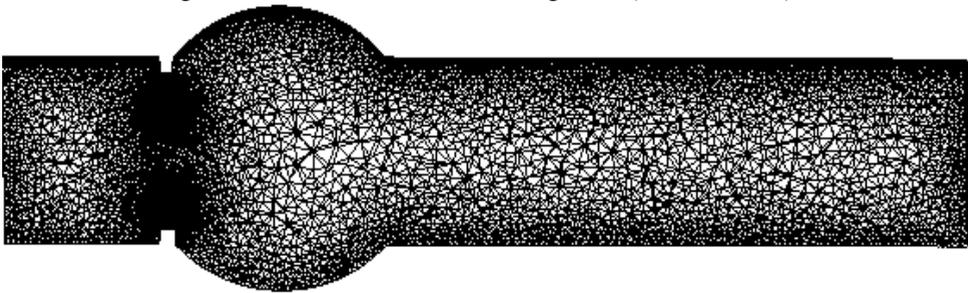


Figure 3. The meshed Geometry

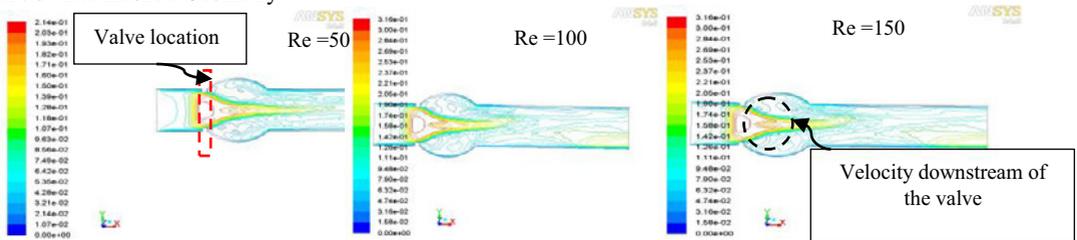
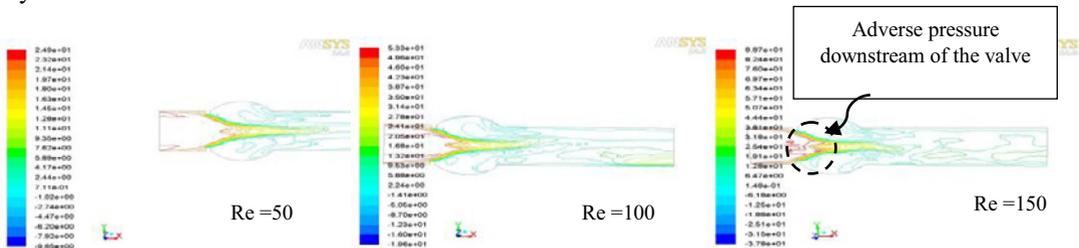
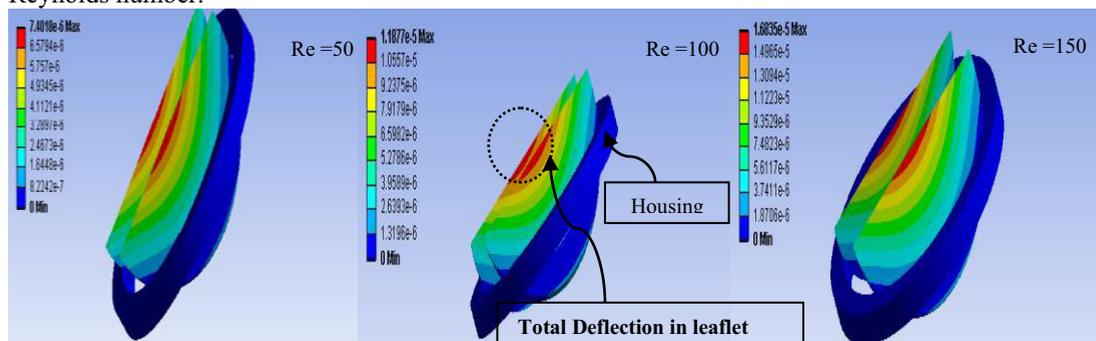


Figure 4. Velocity profile of steady state through an aortic valve in angle in peak systole at different Reynolds number.



**Figure 5.** Total adverse pressure contours, through an aortic valve in angle in peak systole at different Reynolds number.



**Figure 6.** Total deformation contours, in aortic valve in angle in peak systole at different Reynolds number.

It can be concluded that an increase in Reynolds number from 50 to 150 resulted in 10% increase in the induced vibration frequency and 6% increase in the bileaflet valve deflection. The increase in deflection may cause bileaflet deformation and failure in the valve components (bileaflet and connecting pin). This deformation and failure will be investigated further in future studies.

## 5 Conclusions

St. Jude Medical Bileaflet artificial heart valve has been modelled and simulated using CFD and FSI techniques to model the blood flow and the resultant induced vibration. It has been found that an increase in Reynolds number from 50 to 150 resulted in 38% increase in blood velocity and 11% increase in adverse pressure which subsequently resulted in 10% increase in the induced vibration frequency and 6% increase in the bileaflet valve deflection. The increase in deflection may cause bileaflet deformation and failure in the valve components.

## Acknowledgement

The authors acknowledge Universiti Teknologi PETRONAS for sponsoring the research, and the technical assistance for the preparation and presentation of the paper.

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