ASSESMENT OF VORTEX DYNAMIC OF BLOOD FLOW IN MECHANICAL HEART VALVE

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This report is submitted
in fulfillment of the requirement for the degree of
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2019

DECLARATION

I declare that this project “Assessment of Vortex Dynamics of Blood Flow in Mechanical Heart Valve” is the result of my own work except as cited in the references

Signature :...................................

Name : Siti Saiyidah Binti Syed Zainuddin

Date :...................................

SUPERVISOR DECLARATION

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:...................................
Supervisor's Name	: Dr. Mohamad Shukri Bin Zakaria
Date	:...................................

ABSTRACT

These paper represent a computational fluid model. The flow of velocity when blood passes the leaflet in the aortic valve is analysed using computational fluid dynamics. The results show the cause of blood clots. The blood clots happen because of the high velocity occurs. Besides that, wall shear stress with high value also contribute to the blood clotting. Finally, the way to suggest to improve blood clots or reduce the result of velocity and wall shear stress by add the vortex generator on leaflet in MHV. In order to reduce a blood clots, the design of vortex generator also have to be suitable with the leaftlet. There are two method applied to find the result. First step using solid work to design the MHV and software Ansys to find the result.

ACKNOWLEDGEMENT

I would like to thank my supervisor Dr. Mohamad Shukri Bin Zakaria for giving me the chance to undertake a final year project under his guidance for one year. Thank you for always giving me advice and guidance when I am having problems with my final year project. I am grateful for his patience and advice while taking me on this project.

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LIST OF ABBEREVATIONS

MHV	Mechanical Heart Valve
BMHV	Bileaflet mechanical heart valves
CFD	Computational Fluid Dynamic
AHV	Artificial Heart Valve
VG	Vortex Generator

LIST OF SYMBOLS

ρ $= fluid\ density$

μ $= velocity$

k $= turbulent\ kinetic\ energy$

ε $= turbulent\ kinetic\ dissipation$

Eij $= rate\ of\ deformation$

μt $= eddy\ viscosity$

CHAPTER 1

INTRODUCTION

1.1 Background

The heart is a muscle organ that pumps blood to all the organs and cells for them to function. In a healthy heart, the blood flows always in the same direction through the heart. Heart valves keep unidirectional blood flow by the opening and closing of their leaves, which depend on the pressure difference on both sides of the valve leaflets. Artificial Heart Valves (AHV) can be a mechanical or biological substitute to restore the biological function of blood flow transport when anything occurs with natural heart valves such as severe defect or disease (Zhou et al., 2016).

Bileaflet mechanical heart valves (BMHVs) are usually used for valve replacement because their design reduces flow disturbances (Khalili, Ppt, & Ha, 2017). Mechanical valves consist of mechanical components with good mechanical behavior and biocompatibility. BMHV is the most widely used clinical among the various types of mechanical valve (Zhou et al., 2016). This project to study the hemodynamic blood flow in mechanical heart valve for example separation and recirculation.

The present study investigates the blood clotting in mechanical heart valve using ANSYS software. The blood clotting system is the first line of protection of the human body against vascular injuries. When blood vessels are violated, various complex molecular and cellular reactions lead to the formation of spatial-spherical structures comprising mainly small blood cells are platelets and fibrin fibrils, which include the site of injury and stop bleeding (Govindarajan, Rakesh, Reifman, & Mitrophanov, 2016). In ANSYS software can get the result of flow velocity and pressure.

Feng et al in the experiment result found that lower average pressure difference will lead to lower shear pressure in the bloodstream, and thus useful for reducing the damage to the blood component (Khalili et al., 2017). These projects also to study about vortex generator applies to the mechanical heart valve. Vortex generators to gain passive flow control which hypothesis to minimize the shear stress experienced by the blood elements flowing across the BMHV. In this present study also to find the suitable design of vortex generator to apply on the leaflet in MHV. In order to find the right design of vortex generator have to obtain result of lower velocity compare with the design of without vortex generator. If the result is still in high velocity, this present study have to try new design that can reduces the velocity.

1.2 Problem Statement

Mechanical heart valve is prone to blood clotting. Blood clot occurs due to abnormal flow. When blood vessels are violated, various complex molecular and cellular reactions lead to the formation of spatial-spherical structures comprising mainly small blood cells are platelets and fibrin fibrils, which include the site of injury and stop bleeding. The blood clotting system is important because of the first line of protection of the human body against vascular injuries (Govindarajan et al., 2016). The previous study also states that the blood element has been damaged when platelet aggregates are activated because of blood clots (Zakaria et al., 2017). It also shows that another cause of blood clotting occurs because the MHV design is a sharp edge that can contribute to a recirculation area as it is in the increase of the sinus area.

Besides that, the performance of variation of flow velocity and pressure when blood passes the leaflets in the aortic valve. Fluid structure interaction problems due to the opening angles and the internal orifice diameter are not maximized.

In addition, the problem about adds vortex generator on leaflet because to reduce the turbulent flow and pressure differently. In the research of (Dasi, Murphy, Glezer, & Yoganathan, 2008) states that the design of MHV without vortex generator can contribute to thrombosis. From this study also states that in order to avoid the large leaks destroying the structures by adding the rectangular vortex generator. It is just not destroying the large leakage structures but also can decrease local shear of the structure.

1.3 Objective

The objectives of this project are as follows:

a) To study the hemodynamics blood flow in mechanical heart valve for example separation, recirculation

b) To analyze the blood clotting in mechanical heart valve using ANSYS software

c) To study function of flow control vortex generators on leaflets.

1.4 Scope of Project

The scope of present study are:

a) Vortex generator applies to heart valve

b) The flow use in this project is turbulent.

c) The flow field conditions for this study valve are fully opened.

d) The type of heart valve used in this project is the Mechanical Heart Valve.

e) Use of numerical simulation

CHAPTER 2

LITERATURE REVIEW

2.1 Mechanical Heart Valve

Mechanical heart valve (MHV) is a concern for the formation of thrombus because it is necessary to take anticoagulant therapy for the rest of their lives but for the bioprosthetic heart valve (BHV) does not require anticoagulant therapy but the performance decreases after 10 to 15 years (Hedayat, Asgharzadeh, & Borazjani, 2017). In the research (Qiao et al., 2018) found that the formation of thrombus because the shear stress of the pathologist is not normal and changes of blood flows such as blood flow inside arteries were stuck. However, in the studies (Hedayat et al., 2017) found that the formation of the thrombus is started because of the MHV flow through the hinges and leakage in diastole. The condition when the ventricular diastole is completely closed is to ensure the flow is one direction for a healthy aortic valve (Qiao et al., 2018). Based on that statement, the performance MHV and BHV in terms of platelet activation caused by shear stress is in the same state. In this statement it is also possible to see MHV is a better performance than BHV because MHV is required to take therapy for a long time but for BHV performance will decrease after 10 to 15 years.

Another study from (Zakerzadeh, Hsu, & Sacks, 2017) states that important consideration in the choice of MHV or BHV because reintervention due to worsening BHV and it is related to MHV that a long period of anticoagulation. The factor of patient age is having to take seriously because the bad structure of BHV is larger in younger patients but in older patients the risk of bleeding from higher anticoagulation. As can be seen in Figure 2.1, The BMHV is made of round housing and two semi-circular discs, which are installed in housing through a hinged mechanism. Both of these leaflet rotate passively in response to fluid dynamics due to periodic contraction and left ventricular expansion (Spühler, Jansson, Jansson, & Hoffman, 2018).

Figure 2.1: Mechanical Heart Valve, (Spühler et al., 2018)

2.2 Hemodynamic Blood Clot

The leakage blood circulates high velocity values due to the small gap between the two leaflets and the valve housing and the flow circulation significantly located on the head of the valve. Figure 2.2 shows that jet flows occur regularly at first open, close, and completely closed corners. Previous research has found that the occurrence of jet flows is the most harmful flow to the blood cells, which causes blood clots and hemolysis. (Kadhim, Nasif, Al-Kayiem, & Al-Waked, 2017). From this research, fully closed situations are through high velocity values jet flows.

Based on the above statement, we know that high velocity will occur from circulating blood leaks due to small gaps. The higher the velocity value causes blood clotting. In this research that must find a solution to reduce the high velocity.

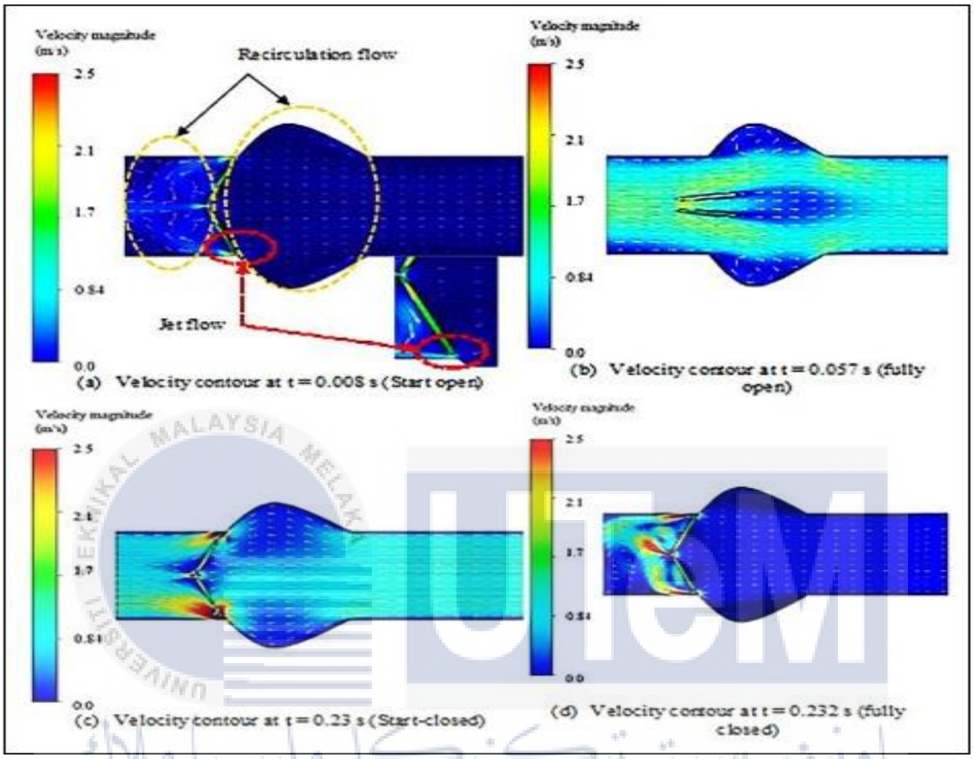


Figure 2.2: Velocity contour during phases of BMHV, (Kadhim et al., 2017)

According to Kadhim et al (2017), “the time value of 0.008 s leaflet valve at the initial open corner, the leakage zone among the leaflet tip and valve housing is at high shear stress value. The shear pressure on the surface of the leaflet is 104.58 Pa. However, the magnitude of the shear stress magnitude between the valve pivot and the housing is 52.3 Pa”. In this research it is found that when taking a long time there will be a high shear pressure. The front of the valve of the mechanical valve has a high shear stress due to the back-blood flow.

This study also shows that the shear stress near the surface of the mechanical valve leaflet continues to increase and reaches 209.13 Pa (Kadhim et al., 2017). Based on Figure 2.3 (b), when the bileaflet is in a fully opened angle, the result of the blood velocity exits at 2.3m / s with 0.057s. It is show that this part has a higher shear stress value. The factors that prove has higher shear stress around the mechanical heart valve are due to the blood flow over the full leaflet strength. Based on the above statements, blood platelet damage will occur as the shear stress values on the valves and pivots are continuously higher than threshold friction pressure.

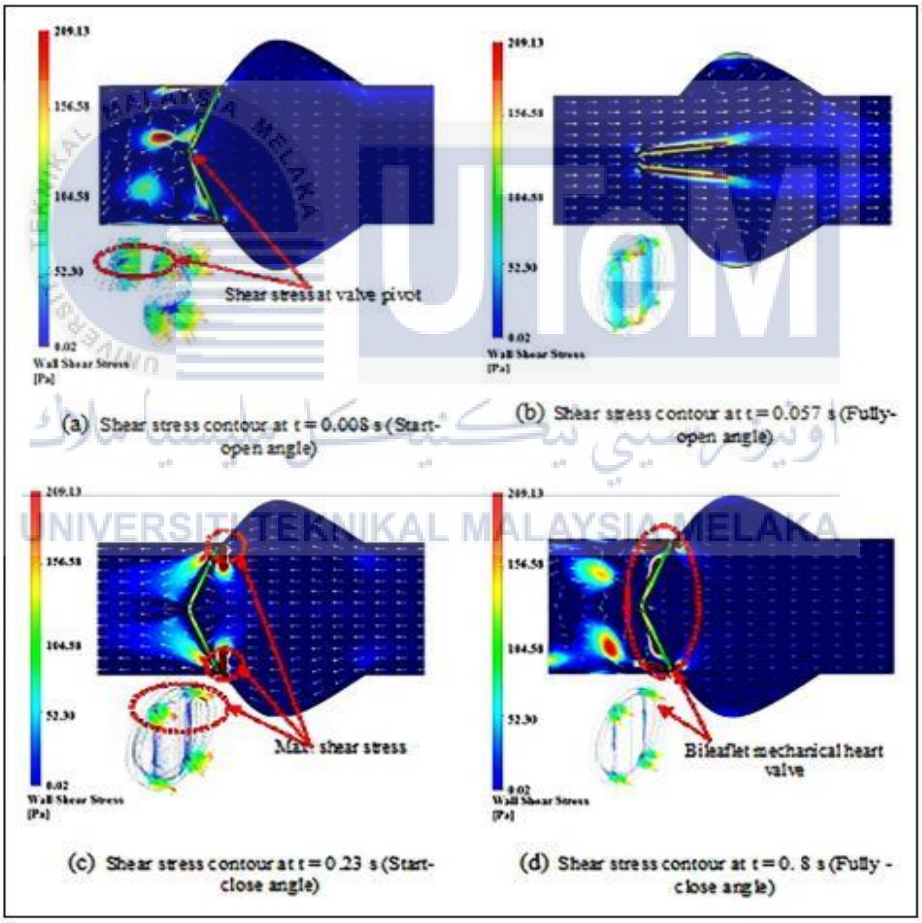


Figure 2.3: Shear stress contour during cardiac cycle for BMHV, (Kadhim et al., 2017)

In the Zhou (2016) study finds that the results for transvalvular pressure difference at various maximum opening angles are shown in Figure 2.4. Based on this result, it shows that the average pressure across the valve decreases significantly when the maximum opening angle increases from 80 to 90. These results show that a greater maximum opening better for lower average pressure difference. (Zhou et al., 2016)

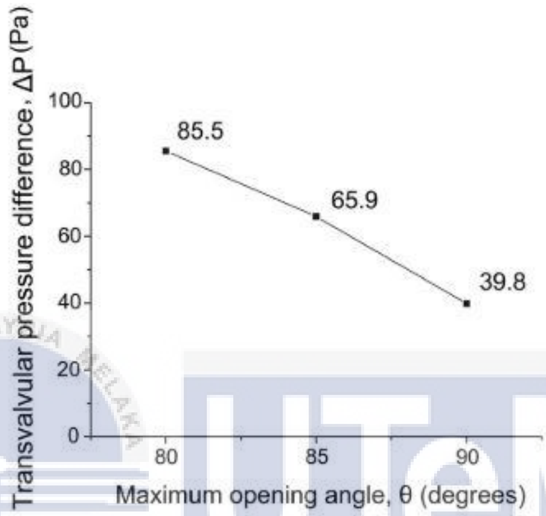


Figure 2.4: Average pressure difference, (Zhou et al., 2016)

2.3 Vortex Generator Application

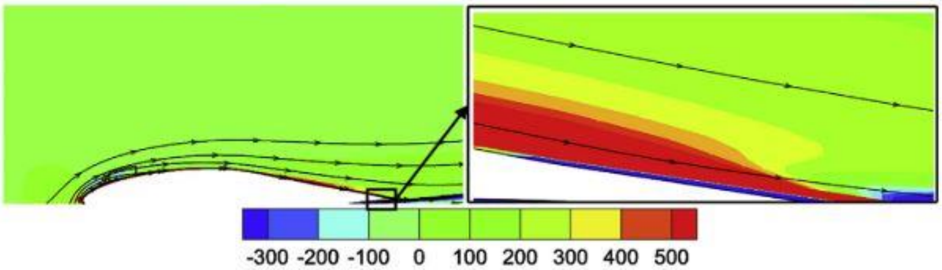
There are three application of vortex generator which is vortex generator effect on aerofoil, vortex generator effects on ship stern flow and vortex generator effects on Mechanical Heart Valve

2.3.1 Vortex generator effect on aerofoil

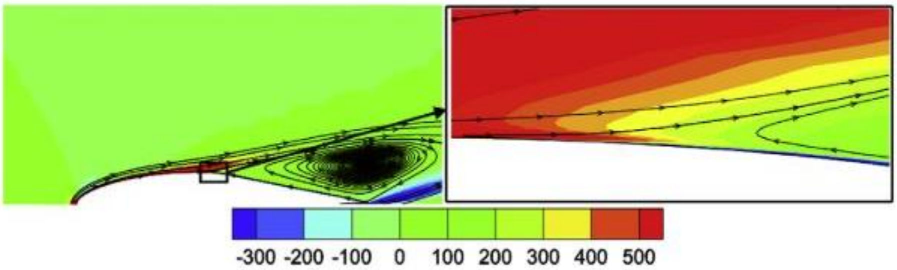
It can effectively improve the aerofoil lift coefficient due to the vortex generator and delay the emergence of the phenomenon. The vortex generator effects in the velocity of inlet and wind turbine rotation speed under uncertain conditions and other effects increase the power of the wind turbine significantly. Torque and thrust are calculated by the momentum theory of blade elements with and without vortex generators and increased by vortex generators. The vortex generator produces a separate vortex. The main region has high momentum fluid that is involved in the boundary layer but for the main region by a separate vortex has low momentum fluid of the boundary layer. This result shows that the vortex generator is efficiently controlled the separation of the flow.

The effect of the vortex generator can decrease the thickness of the boundary layer and drag coefficient also can reduce at a certain angle. If the angle of attack is high, it can improve the coefficient of lift and double vortex generator can reduce the thickness of the boundary layer. This result shows good control separation of the flow when has double vortex generators.

Figure 2.5 shows the angle of attack is equal to 14^{o} and streamline near the aerofoil with the vortex generator. There is no reverse flow phenomenon because of the vortex generators in the boundary layer of the suction surface. The x velocity gradient is greater than zero when the vortex generator is mounted on the edge of the aerofoil suction surface. The condition of the clean aerofoil when x velocity gradient is less than zero and separation of the flow occurs. In the same position, the fluid keeps the flow direction and the x-velocity gradient of the fluid is greater than zero. Based on this result, the effect of adding a vortex generator can alter the boundary layer flow. Besides that, in order to maintain the flow direction and stagnation fluid particles not occurs in the boundary layer must ensure that liquid momentum is sufficient for the boundary layer.. Then, it controls the flow separation and transforms the fluid flow properties around the aerofoil by adding a vortex generator (Wang, Zhang, Qiu, & Xu, 2016).



(a)



(b)

Figure 2.5: Aerodynamics flow characteristic at aerofoil for (a) with vortex generator (b) without generator, (Wang et al., 2016)

2.3.2 Vortex generator effects on ship stern flow

A utilize of vortex generators as a stream control gadget is broadly utilized to decrease division in different streams such as aircraft wing, car, truck, train and airplane. The small wings with different plan geometry are called vortex generators. The separation of the stream can be delay in a thick boundary layer with a vortex generator in the full shape hull flow. Based on this study, the transfer of high energy liquids to the surface of the hull is due to the value of the vortex generator that expands the vortex at the top of the boundary layer. This result shows the smooth surface is improved as the kinetic energy on the surface, the flow can endure greater different pressure gradient before separation occurs (Falchi et al., 2014).

2.3.3 Vortex generator effects on Mechanical Heart Valve

According to the (Dasi, Murphy, Glezer, & Yoganathan, 2008), the factor occurred of coagulation is because of high shear stress. It will affect red blood cells or platelets will become active. If active platelets occur, they can cause coagulation as well. In this study also states that red blood cells are exposed to damage at shear stresses of 10-100 dyn/cm2 to 500 dyn/cm2 ability of platelets to combine several elements can cause thrombosis. Besides that, this research found that the effect of a rectangular VG case not only scatter and destroys the structure of a large leakage flow structure but also reduce the local shear. Based on the figure 2.6 d-f, it indicates that the amount of vortex attention is obviously the lowest for a rectangular VG case while in based on figure a-c is a case of without VGs indicates of a coherent vortices structure which is strong transient jet emanating. This vertical distribution shows high shear and high rotating shear flow that forms the flow of leakage jets. In this we case, we can conclude that high shear stress occurs without VGs which is can cause thrombosis. It is good to add a rectangular VG that does not destroy large leakage structures but reduces local shear.

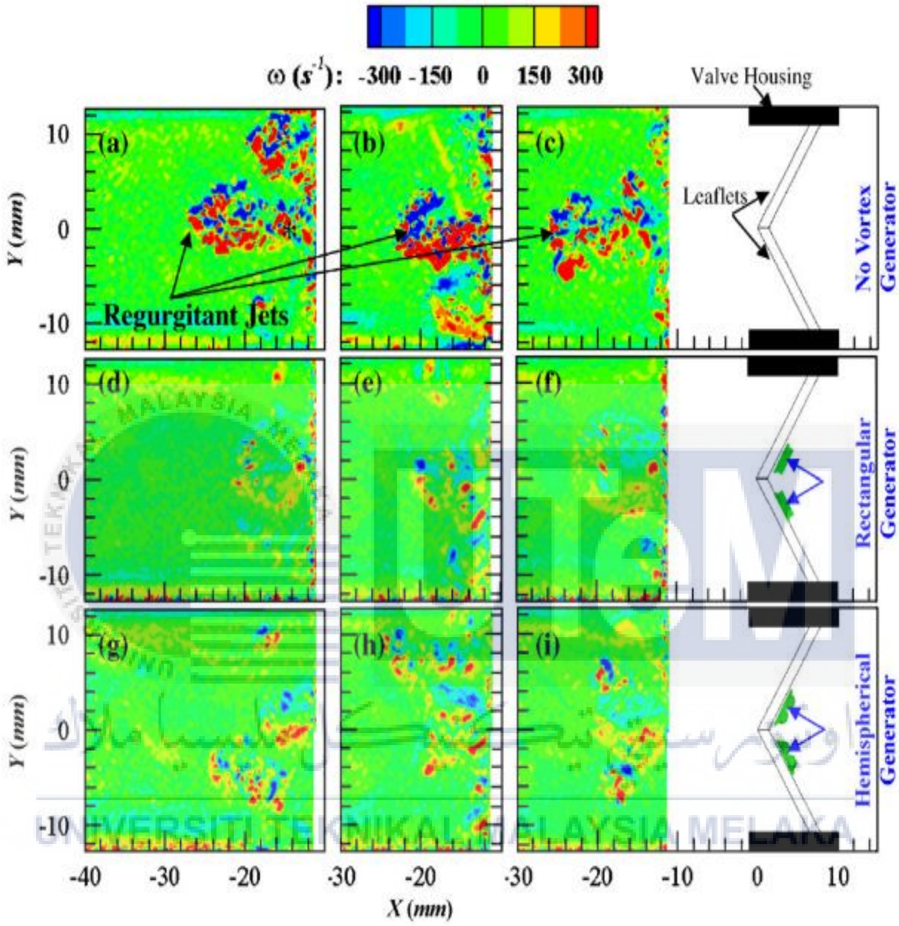


Figure 2.6. Three immediate of field at the time of closing the valve: (a–c) no vortex generator, (d–f) rectangular vortex generator, and (d–i) hemispherical vortex generator.

Other previous studies from (Murphy, Dasi, Vukasinovic, Glezer, & Yoganathan, 2010) found that most of the VGs consist of blades with small corner proportions mounted to the surface at one point to the nearest system. The vortex generator works passively by producing a smooth vortex of the flow close the wall, thereby reversing the wall flow near big scale motion and reviving the boundary layer. In the other previous study (Engineering, 2018) states to improve the reduction in pressure gradients by adding the counter rotating vortex generator. In order to know how strongly the counter rotating vortex generator on the leaflet is to know the type of flow separation first. In this previous study showed that adding a vortex generator could reduce the cause of blood clotting in the MHV.

Figure 2.7: The design of counter rotating vortex on leaflet

2.4 CFD in Mechanical Heart Valve

Comparison of simulation results with experimental results provides valuable critical mechanisms to ensure that simulations in fact realistic. However, a constant challenge in reinventing the vivo environment in vitro is to build physiological phantoms that behave physiologically in terms of the interaction of the fluid structure. Vascular phantoms with a extend of Young's moduli and Shore harness that cover with in vivo conditions can be 3D printed but separating the vascular geometry within the research facility in this manner taking off numerous structures and elements accessible in vivo, fundamentally restricting the degree to which the vivo circumstance can be replicated. The capacity to reabsorb in vivo's condition anatomically and mechanically remains a issue that cannot be unraveled (Randles, Frakes, & Leopold, 2017)

The important part in the diagnosis and management plan is quantification hemodynamic including the velocity and pressure field because of the patient for patients suffering from cardiovascular disease. Understanding of the principles governing localization and the progress of vascular disease has become a long-term goal for computing biomechanics. There is a model used to get these standards expanded from 2D to a 3D numerical strategy to characterize to the human vascular framework. The simulation in 2D frequently considers the symmetry of the result on the centre axis. There are some outstanding references about the broad spectrum of CFD models

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the methodology used in this project to obtain data input for the blood clots in Mechanical Heart Valve. The flow chart of the project is shown in Figure 3.1. This research starts by studying of a clean leaflet of Mechanical Heart Valve and do a simulation clean leaflet using Ansys software. The validation outcomes are done by regarding clean leaflet is based on a journal that has similar details. The first step is doing a pre-processing, the geometry of clean leaflet of MHV is drawn by using SolidWorks software with the same parameter of the published journal. After that, the geometry import into the Ansys workbench 16.0 software for mesh generating. After simulating clean leaflet of MHV, identify the separation of flow result whether the result is the same as the result from the journal that had been doing for reference. The result will come out with wall shear stress and velocity. From the result, the factor of blood clot occurs can be identified. This simulation must get a solution to reduce blood clots such as the pressure and velocity must get lower value in order to reduce blood clots.

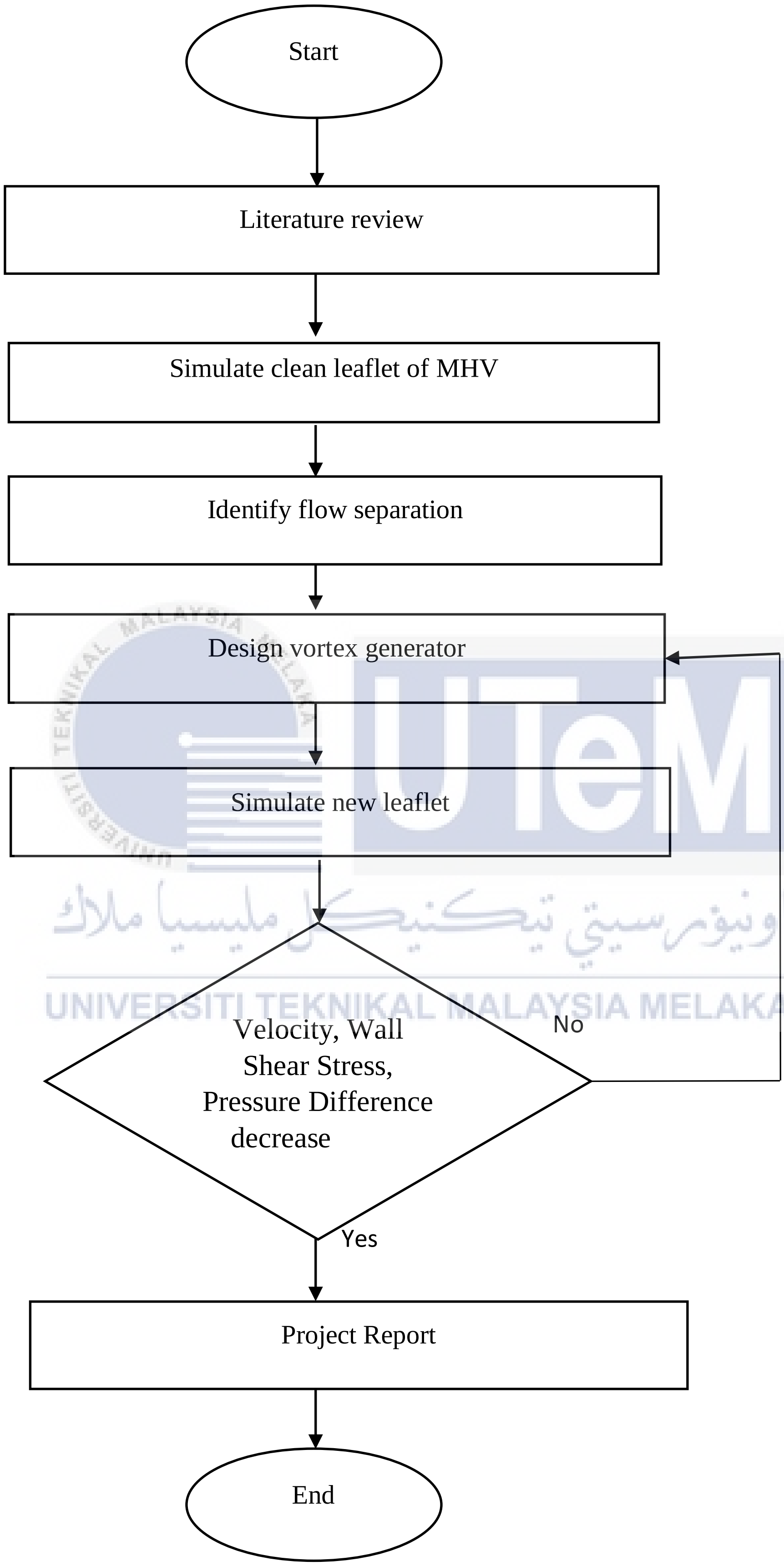


Figure 3.1: Flow chart of the methodology

3.2 Governing Equation

3.2.1 Navier-Strokes Equation

Blood flow is governed by the incompressible Navier-Stokes equation. The effect of a thrombus on the blood flow is represented through a reduction of fluid velocity in the region occupied by the growing thrombus. The general equation of motion to evaluate the blood glow of fluid domain, in 3D with Cartesian coordinates, are Navier-Strokes equation:

Incompressible continuity equation:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\frac{\partial u}{\partial x} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + v\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right)$$

$$\frac{\partial v}{\partial x} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial y} + v\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial x^2}\right)$$

$$\frac{\partial w}{\partial x} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial z} + v\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

The ρ represents the density of fluid (kg m^{-3}), u, v, w represents the velocity in x, y, z direction (ms^{-1})

3.3 Validation

The study of (Zhou et al., 2016) is selected as a validation reference. Table 3.1 shows the parameter from the journal that used to simulate clean leaflet of MHV and figure 3.2 show the geometry.

Parameters	**Dimensions**
Velocity inlet	0.32 m/s
Blood density	1056 kg/m^3
Kinetic viscosity	0.0035 kg/ms
Outlet pressure	0 Pa

Table 3.1: Parameter of the simulated clean leaflet of MHV

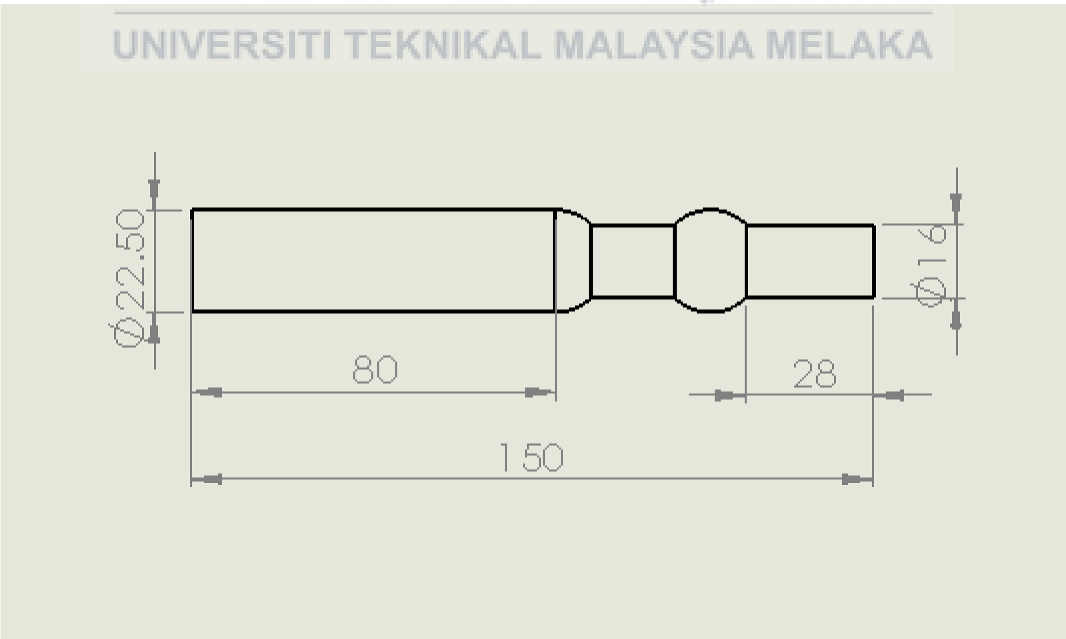


Figure 3.2: Geometry of MHV

3.4 CFD Simulation Setup

In order to conduct simulation required by using CFD, there are three steps are needed in sequence to be performed which are pre-processing, solver and post-processing.

3.4.1 Pre-Processing

In the pre-processing stage, the activity required is geometric creating SolidWorks, continuum region refining, boundary name creating and mesh generating. The clean leaflet of MHV is designed on the geometrical parameters provided published journal. Parameter of geometry design is not fully provided in the previous journal. After that, the completed clean leaflet of MHV will be exported to Ansys for meshing.

Boundary Name Creating

The geometry was labeled by creating name selection for velocity inlet and velocity outlet in order to simplify the procedure.

Part	A	B
Name selection	Velocity Inlet	Pressure Outlet

Table 3.2: Name selection for geometry part..

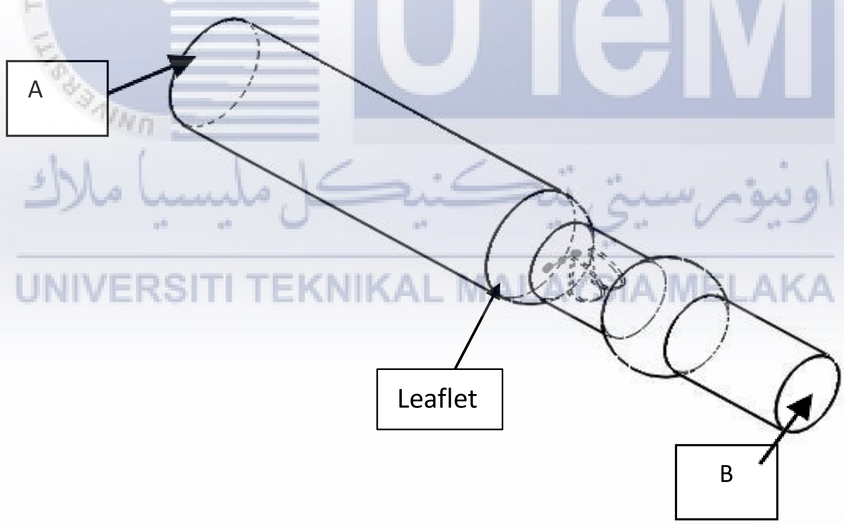


Figure: 3.3: Name selection part of geometry

Grid Generating

Grid Generating process after defined the name selection for each face. The complex of geometry is meshed by a polyhedral mesh grid to increase computational efficiency. The number of meshing elements for without vortex generator gets in this study is 77520 and the number of nodes is 426508. Figure 3.4 shows the view of the polyhedral meshing.

Figure 3.4: Polyhedral meshing grid

3.4.2 Solver

In the solver process, the pressure and velocity formulation are chosen in this study. Due to this simulation involved clean leaflet to detect occur of a blood clot. The properties of details in the present study are keeping as a reference without changing its properties such as the inflow velocity 0.32 m/s and blood density 1056 kg/m^3.

3.5 Geometry Vortex Generator

Based on Figure 3.5, it shows a double vortex generator on the leaflet. In the previous study states that a double vortex generator will reduce the shear stress. According to (Murphy et al., 2010) states that a rectangular VG does not destroy large leakage structures but reduces local shear. There are two types of vortex generator to obtain a lower velocity and average pressure in this present study. First design is with double vortex generator. In this present study, we choose to design the four of vortex generator on the leaflet in MHV. It is because to obtain lower velocity compared to the design which is not with vortex generator.

Based on the first design which is Figure 3.5, it obtain of high of velocity more than the without vortex generator. Based on the first design, the angle of the flow is big than the second design. In order to obtain lower velocity in this present study, the other design of vortex generator by refer to the previous study of (Engineering, 2018) which is states that the vortex generator can reduces the local of shear. By referring to the previous study, there are new design with four of vortex generator on the leaflet. By adding the vortex generator, the velocity is reduces which is also can reduces the causes of blood clotting in the patient’s life.

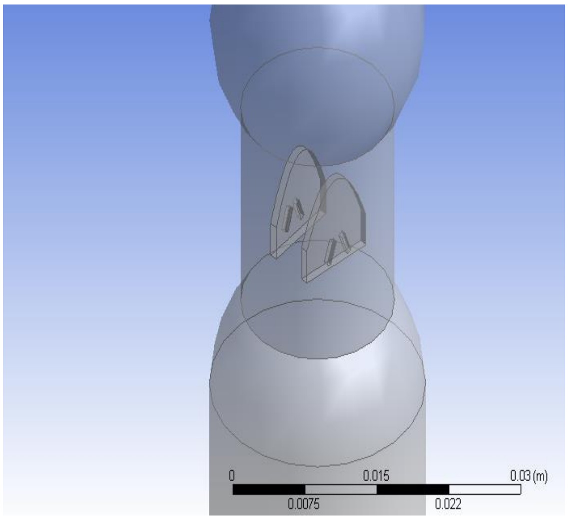


Figure 3.5: Design of double VG

Based on the figure 3.6, this design of vortex generator is upgrade with four of vortex generator. In order to reduce the velocity, four of vortex generator were added on the leaflet. In this present study, the design of four vortex generator was choosen to reduce blood clots.

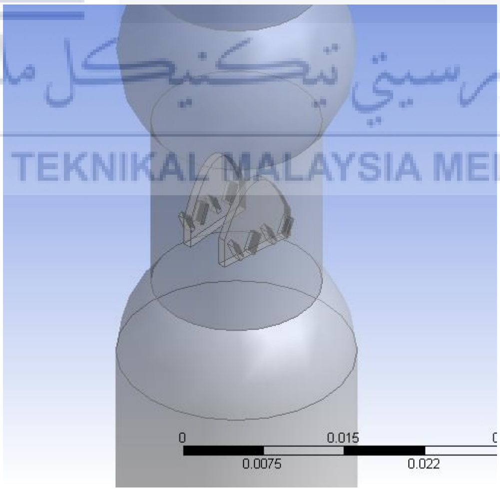


Figure 3.6: Design of four VG

CHAPTER 4

RESULTS AND DISCUSSION

The preliminary result of simulation clean leaflet of Mechanical Heart Valve to compare the result with the journal had been to do reference. After finish result with no vortex generator. It will proceed with the new design with the vortex generator. The next simulation will do with the new design which is added vortex generator on the leaflet of Mechanical Heart Valve.

4.1 Grid Independency Test

Grid independency term is a term used to describe increase improvements by using smaller cell sizes for computation. The calculation should approach the correct answer when the mesh becomes more refined, therefore the grid convergence run. In order to use grid independence test, the number of element and node are increased per calculation until the present result shows no difference as a previous result. After finish the grid, it has to move with the final simulation. There are three types of meshing which are coarse, medium and fine type.

Number of mesh element	Volume flow rate (m/s)
22195	0.45
22179	0.45
37927	0.45

Table 4.1: VG Grid Independency Test

4.2 Validation

The result of validation with the previous journal results form an important part of the successful CFD analysis. Successful validation is getting similar parameters with the previous study. The most important characteristic is to find appropriate velocity with the previous study by following the geometric, velocity inlet, blood density, kinetic viscosity and outlet pressure value.

Figure 4.1 shows the previous result with (Zhou et al., 2016) which is the value of velocity is 0.59 m/s. Figure 4.2 shows the result of the present study simulation which is the value of velocity is 0.47 m/s. From the validation result, there is a difference between present studies with the previous study of 0.12. There is a difference in the results with the previous study probably because it does not follow all the actual parameter of the geometry drawing. Parameters of geometric drawing information are not fully provided in the previous study (Zhou et al., 2016). The other reason might be because the value set in the setup of simulation difference from previous study.

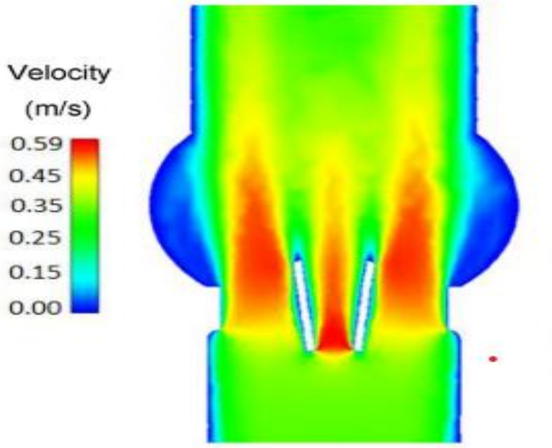


Figure 4.1: Velocity contour at the centre plane of the MHV (previous study)

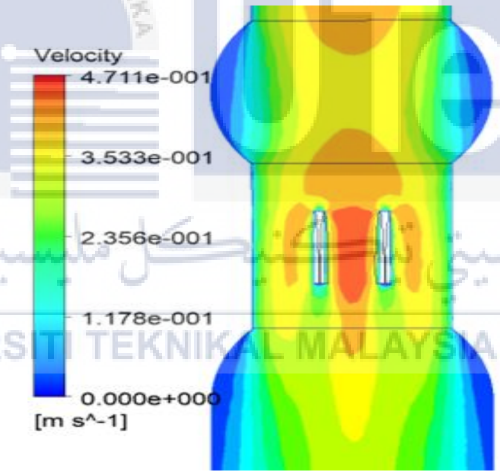


Figure 4.2: Velocity contour on the centre plane of the MHV (present study)

The convergence criteria for each equation are set to 1e-3. Figure 4.3 and 4.4 shows the result calculation of iterations.

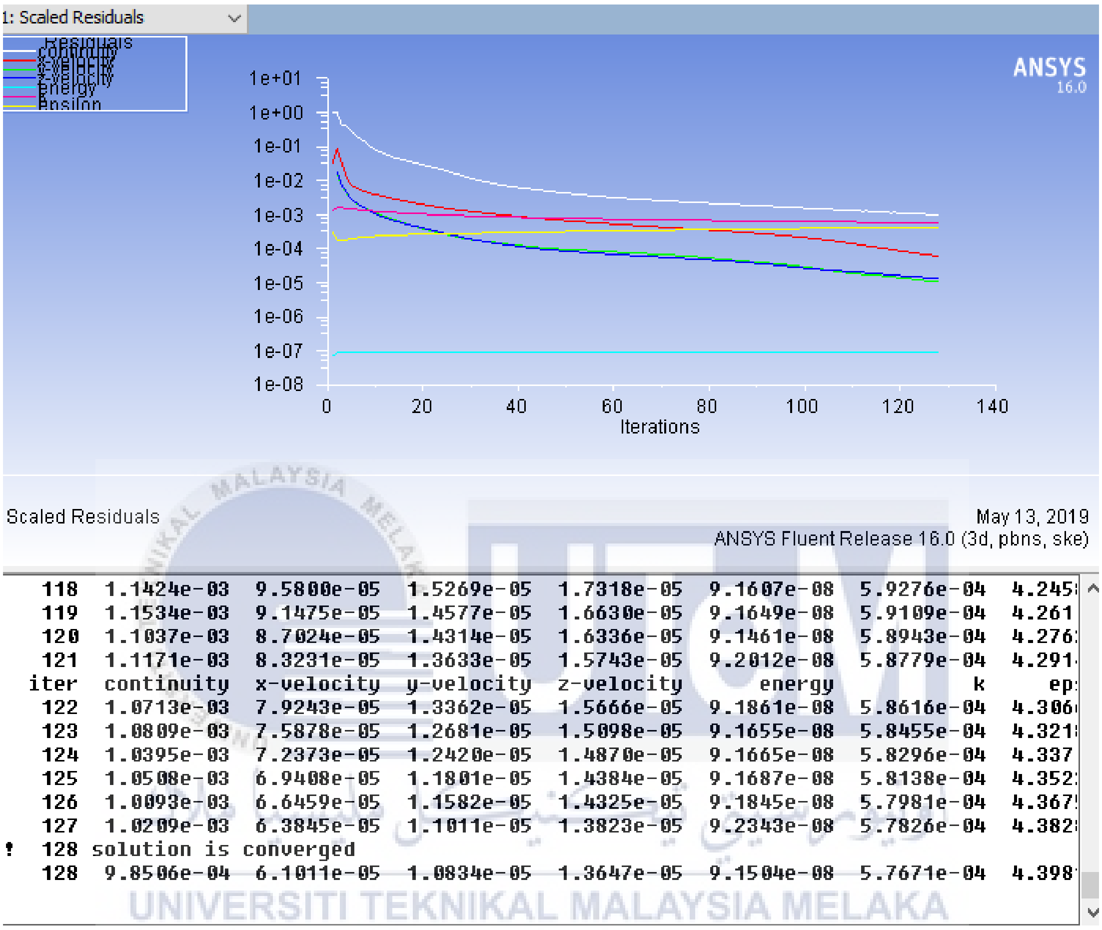


Figure 4.3: The result calculation of iterations.

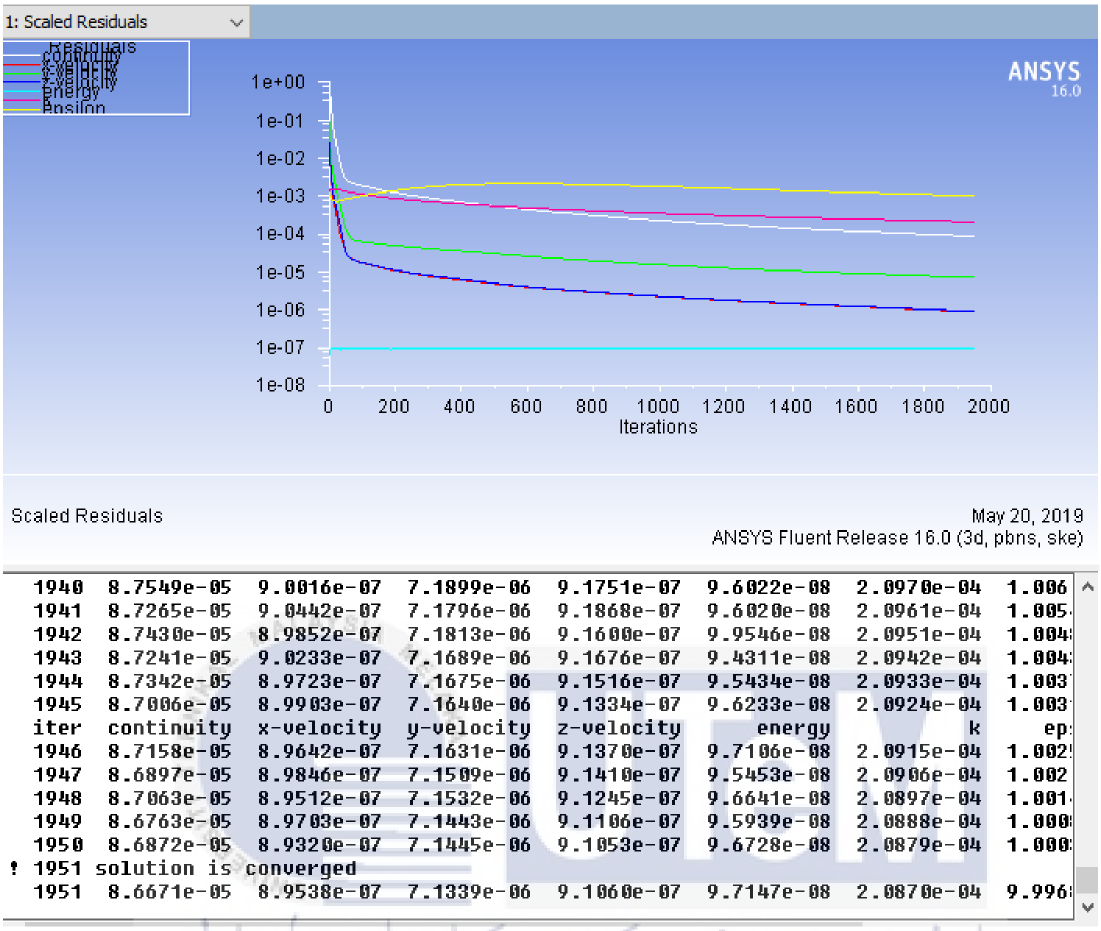
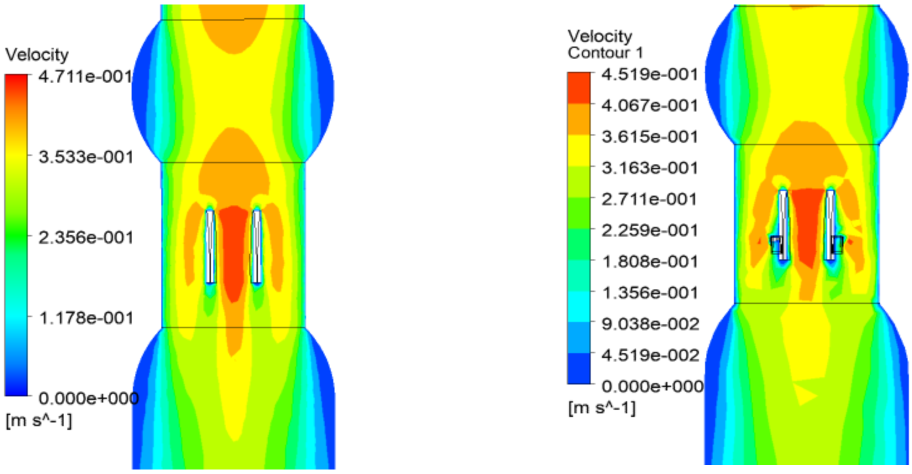


Figure 4.4: Result convergence with vortex generator

4.3 Comparison of Flow Characteristic between VG and No VG



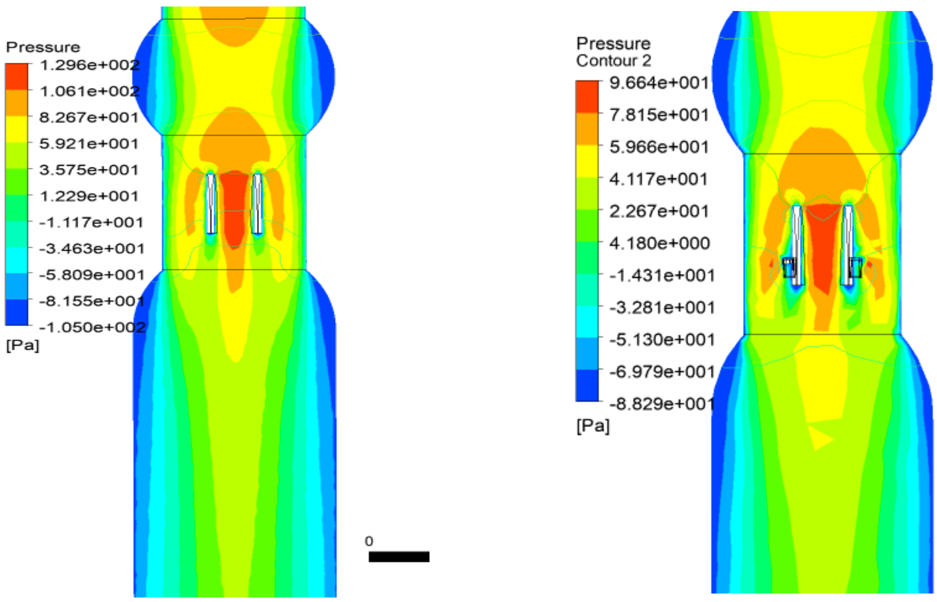
0.47 m/s | 0.45m/s

(a) without vortex generator | (b) with vortex generator

Figure 4.5: Velocity for (a) without vortex generator and (b) with vortex generator

These results indicate that higher velocity occurs when blood passes the leaflets in the aortic valve. It shows that the flow of the blood is not normal. The higher the velocity value may cause blood clotting.

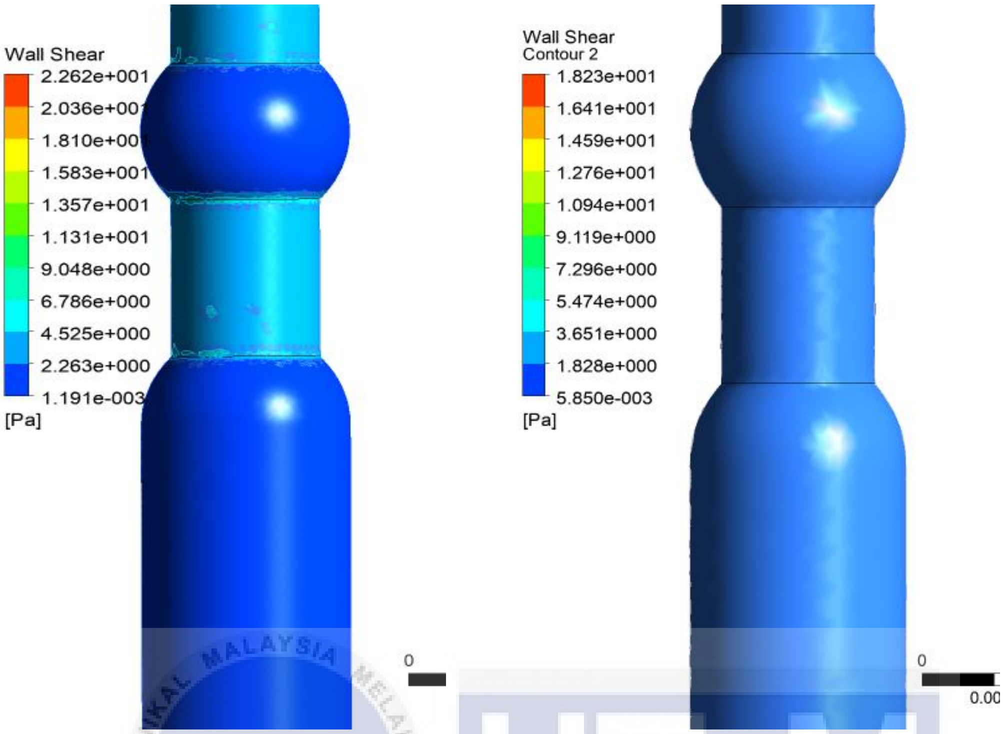
The value of velocity occurs without the vortex is 0.47 m/s. It shows that the value of velocity is higher with no vortex generator. This higher value of velocity will cause of blood clots. The way to solve this higher velocity is by adding the vortex generator on the leaflet. After adding the vortex generator on the leaflet, the value of velocity is reduced. The value of velocity with the vortex generator is 0.45 m/s. It indicates that the value is at a lower velocity. 0.02 m/s velocity difference was obtained with the case without any vortex generator.



(a) without vortex generator (b) with vortex generator

Figure 4.6: Pressure for (a) without vortex generator and (b) with vortex generator

Based on the figure 4.6 (a) with no vortex generator, it shows that the pressure is higher. Based on the figure 4.6 (b) above with the vortex generator, it shows that the pressure is lower. When the pressure is increase, blood clots will occur because of the high pressure. It show that the result after adding the vortex generator on the leaflet, the value of pressure is reduced. The value of pressure with a vortex generator have to obtain lower than without vortex generator. It is because the lower value of pressure can reduce blood clots.



(a) without vortex generator (b) with vortex generator

Figure 4.7: Wall shear stress for (a) without vortex generator and (b) with vortex generator

Based on Figure 4.7, it shows that wall shear stress value without vortex generator is higher value. The wall shear stress value with the vortex generator is a lower value that can prevent the occurrence of blood clotting. In the previous journal states that the higher shear stress occurs of blood clots (Zhou et al., 2016). In this present study, it is necessary to find lower wall friction pressure to prevent blood clots from occurring.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In conclusion, there is important to understand about the problem happen with MHV. Blood clots are dangerous that may cause death to the person. In order to avoid this blood clots, there is research that needs to explore. The high shear stress and pressure is one of the causes of blood clotting. There is a lot of the previous study that states the cause of blood clotting. The other way to reduce the value of shear stress and average pressure is to adding the vortex generator. There is also the previous journal that states the function or effect of vortex generator such as application of vortex use in aerofoil and ship stern.

In this present study, there is a problem when adding the vortex generator. There are might be because of the different sets of boundary conditions. Besides that, there are a different number of elements of meshing. If the value of meshing is the same, it will obtain a high value of skewness at the meshing of vortex generator geometry. Other reasons may be because the parameters of the vortex generator do not correspond to the leaflet.

Based on my observation, there are several recommendations throughout this present study. The number of elements of meshing has to increase to obtain a better result. The value of skewness must obtain lower than 0.8 for the best of meshing. Besides that, the value of boundary condition of vortex generator and without vortex generator must set in the same value for getting better of comparison of velocity and wall shear stress.

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