THE UNIVERSITY OF VERMONT
COLLEGE OF ENGINEERING & MATHEMATICAL SCIENCES

THE University of Vermont MEDICAL CENTER

Team 13: The Bernoulli Heart Valve

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Introduction and Background

Edwin Taylor Haring M.D. is an anesthesiologist resident at The University of Vermont Medical Center (UVMMC). He envisioned a novel leaflet geometry that will allow a greater opening angle for heart valves since a shallow angle increases hemolysis and clotting. Patients with heart valves must concurrently take anticoagulant medication to mitigate embolism-related injury such as heart attack, stroke, and pulmonary embolism. Reducing the need for blood thinners allows more effective clotting and minimizes the risk of hemorrhaging from minor or major injuries. Dr. Haring's key requirements were:

- Implement the novel airfoil leaflet geometry
- Ensure closing after reaching an opening angle of 90°
  - Airfoil leaflets induce a pressure differential between opposing sides of the leaflets.
- Leaflet shear must fall below accepted threshold to prevent clotting

Working Design Concept

To properly investigate the concept of an airfoil leaflet via computational methods:

- A 2D design was created first (Figure 1), followed by an improved 3D design (Figure 2)
- Theoretically, the airfoil shaped leaflets create a pressure gradient and forces a velocity change that allows the leaflets to open fully to 90 degrees and close in reaction to reverse flow (Figure 2)

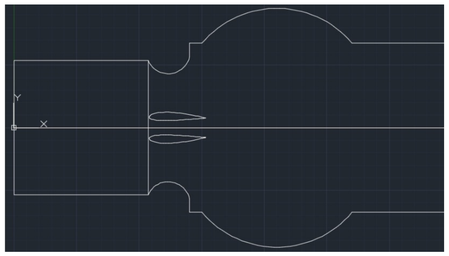

Figure 1: 2D working design concept

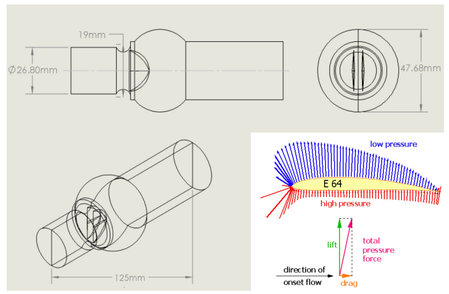

Figure 2: 3D working design and airfoil concept

Methods

Computational methods were used to analyze the airfoil leaflet design which involves:

1. Create CAD design (See Working Design Concept)
2. Develop mesh from CAD design (Figures 3, 4)
3. Set up ANSYS Fluent simulation software
   a. Define boundary conditions (Figures 3, 4)
   b. Implement pulsatile flow equation to mimic heartbeat flow (Figure 5)
4. Obtain desired results from simulation (Figure 6)
   a. Velocity and pressure distributions, wall-shear

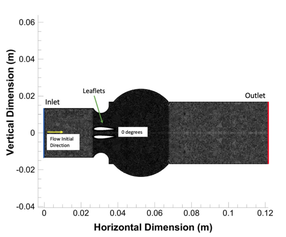

Figure 3: 2D Mesh

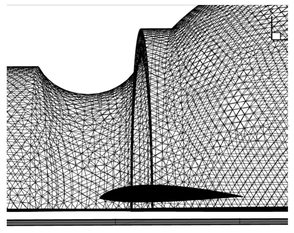

Figure 4: 3D Mesh

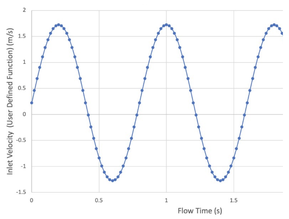

Figure 5: Graph of Pulsatile Flow

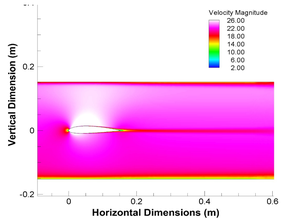

Figure 6: Velocity Contour Plot

Verification Results

1. Surrounding Leaflet Flow Velocity and Pressure

The pressure and velocity surrounding the airfoil leaflet is a primary parameter that determines the leaflet behavior. Steps 1-3 of the Methods section, explain most of the techniques for this verification. The contour plots of pressure and velocity can be obtained from Tecplot. The contour plots provide a map of the magnitude values for the parameter being analyzed.

Figure 7 displays a clear pressure gradient for both angles, with the pressure of greater magnitude below the airfoil and a lower magnitude above the airfoil. This is expected as reverse flow is caused by diastole, which is when the gradient should appear to close the leaflets and prevent back flow. The contour plots suggest that the airfoil leaflet design helps induce a pressure gradient that would ensure proper closure of the valve from a fully open position.

Verification Results Continued

2. Wall and Leaflet Shear

Shear is the parameter being investigated, which is measured via flow time across the pulsations. Steps 1-3 of the Methods section explain the techniques for this verification, and ANSYS Fluent was used for measuring the shear on the leaflet and wall of the domain. The surface shear experienced by the leaflets and top wall shall be below the threshold for hemolysis, 150 Pa.

The peaks in Figure 9 (right) correspond to higher velocities during systole whereas the lower peaks correspond to lower velocities during diastole. The airfoil leaflet and domain had a max shear of 16.10 Pa which is a value well below the desired threshold. It is important to ensure the shear values remain low to prevent hemolysis which can lead to further valve complications.

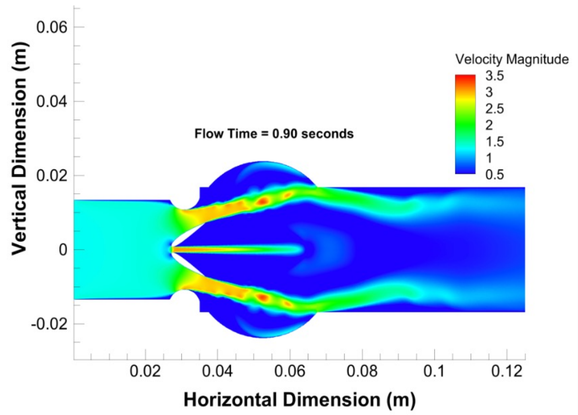

Figure 7: 2D Velocity Contour at 35 Degrees

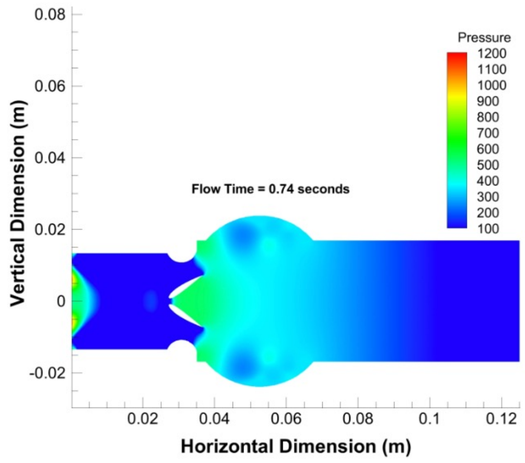

Figure 8: 2D Pressure Contour at 35 Degrees

Verification Results Continued

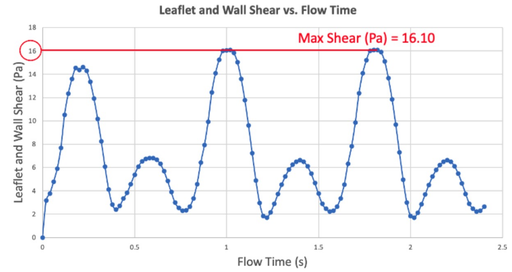

Figure 9: 2D Wall and Leaflet Shear at 35 Degrees

Conclusions

Goal: Investigate the potential advantages of implementing airfoil leaflets to determine if the design improved the ability for the leaflets to open and close reliably from 90 degrees.

- By analyzing different leaflet angles with static 2D and 3D simulations, the data suggests that the airfoil design does help induce a sufficient pressure gradient allowing for the leaflets to open and close to as close to 90 degrees as possible.
- The shear on the 2D and 3D airfoil leaflets was within an acceptable range, confirming the new geometry would be feasible from a biological standpoint.
- The pass rate for the defined engineering specifications is: 90%

Future Work

- The next key step is to take the pre-existing 3D static models and implement dynamic leaflets as this ensures confidence in results while also emulating a human aortic heart valve.

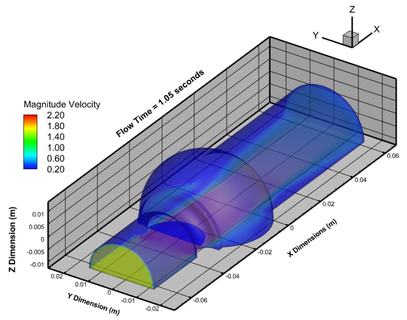

Figure 10: 3D Static Pressure/Velocity Contour Plot

Acknowledgements

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