Heart Valve Dynamics During a Cardiac Cycle

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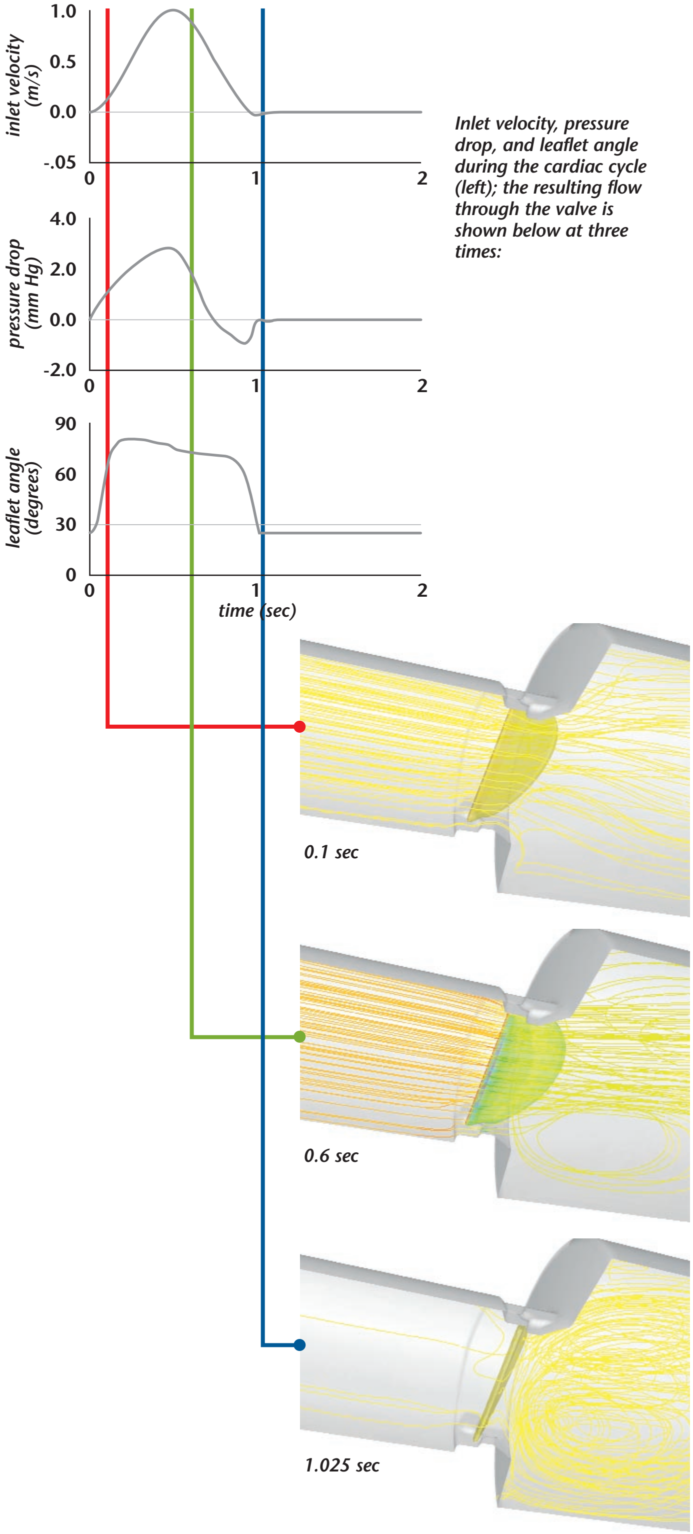

Inlet velocity, pressure drop, and leaflet angle during the cardiac cycle (left); the resulting flow through the valve is shown below at three times:

The interaction between blood and the structures that transport it plays an important role in many biofluid dynamic flow problems, such as blood flow in the heart and vessels, through heart valves, in cardiac assist devices, and in artificial organ design. Different numerical techniques have been used to tackle this fluid-structure interaction (FSI) problem. At Ghent University, a new fluid-structure interaction model has been developed that is based on the dynamic mesh model in FLUENT. The model has been used to simulate a prosthetic aortic valve, and the results have been helpful for visualizing the blood flow in the region of the valve throughout a cardiac cycle.

The FSI technique was implemented in FLUENT using journal files and user-defined functions (UDFs). An external FSI code (written in C++) drives the transient calculation. This code runs a subiteration loop for every timestep in order to solve the fluid-structure interaction problem. During every subiteration a journal file with FLUENT commands is produced by the FSI code and executed by FLUENT. In this journal file an estimation of the position of the valve is calculated in a “Define on Demand” UDF. This valve position is used in the “Define Grid Motion” UDF for the dynamic mesh model, and the corresponding flow field is computed. Once the solution converges, the forces on the leaflet are calculated using another “Define on Demand” UDF. When the first subiteration finishes, the external FSI code checks the convergence criteria for the fluid-structure interaction problem. If certain criteria are not met, a new subitertion is started. The valve position is adjusted using a stabilizing subiteration scheme that uses a numerical derivative of the moment on the leaflet[1], and a new flow solution is computed, starting from the results at the previous time. This process continues until the prescribed conditions are satisfied, at which point the time is incremented by the FSI code, and a new valve position for a new time is computed. Using between three and four subiteration loops, the FSI problem typically converges to within 3 or 4 orders of magnitude before the next time step is started. A fully implicit coupling procedure is therefore achieved by using a separate solver for the fluid problem (FLUENT) and for the structural problem (the FSI code).

Initial tests of the model were performed on a 2D case that illustrated the dramatic change in the flow in the aortic sinus during a cardiac cycle (**http://navier.ugent.be/~kris**). More recently, a 3D simulation involving 500,000 cells has been performed to track the blood flow and motion of one leaflet of a bi-leaflet heart valve for a complete cardiac cycle. Clinical and *in vitro* studies show different dynamic behavior under different physiological conditions, such as aortic versus mitral position, and the expected flow patterns and leaflet movement can be predicted by the FSI results. The FSI model could therefore be an important means of better understanding the phenomena that drive the coupled behavior of blood flow and artificial heart valve leaflets. This new FSI algorithm has promise as a major engineering tool for unraveling the hemodynamics associated with thrombolitic and hemolytic events of existing and new mechanical heart valves. ■

reference:

1 J. Vierendeels, K. Dumont, and P. Verdonck, 33rd AIAA Fluid Dynamics Conference and Exhibit AIAA–2003–3720, pp.23-26, June 2003.