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Fluid-Structure Interaction and Multi-Body Contact. Application to Aortic Valves.

*** M. Astorino[1], J.F. Gerbeau[2], O. Pantz[3] and K.F. Traoré[4]**

[1] INRIA Paris-Rocquencourt
78153 Le Chesnay Cedex, France
matteo.astorino@inria.fr

[2] INRIA Paris-Rocquencourt
78153 Le Chesnay Cedex, France
jean-frederic.gerbeau@inria.fr

[3] École Polytechnique
91128 Palaiseau Cedex, France
pantz@cmapx.polytechnique.fr

[4] Université Pierre et Marie Curie - Paris VI,
75013 Paris, France
karim.traore@inria.fr

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ABSTRACT

In the cardiovascular system, valves play a key role in regulating blood flows. Opening and closing in sequence with each heartbeat, they let the blood flowing in one specific direction, preventing at the same time its back flow [3]. Important cardiovascular diseases, like subvalvular stenosis or valvular regurgitation, are associated to complex interaction between the blood and the leaflets of valves. From a medical point of view (e.g. for the construction of artificial valves), it is therefore extremely important to understand the fluid-mechanical phenomena that happen in the neighborhood of real valves. Since numerical simulations can give an insight into blood flows, they could be used in the case of valves to improve clinical decisions.

To simulate numerically the movements of a thin valve immersed in an incompressible viscous fluid, two main aspects have to be considered: the fluid-structure interaction (FSI) between the fluid and the solids and the contact that could happen among the leaflets of the valve during its closure. Here we present a numerical method that handles both of the problem, preserving at the same time the modularity of the fluid and structure solvers. The whole numerical procedure is based on a partitioned scheme where a master program exchanges the information between fluid and structure. In this sense the two solvers are kept distinct and independent.

The FSI problem is discretized using a finite element approach and solved with a “Fictitious Domain” method implemented in the partitioned scheme, as proposed in [1]. At the closure of the valve, the contact among leaflets is handled with a contact algorithm. The hypothesis of non-penetration among solid objects defines a non-convex optimization problem. Among the different strategies to solve the latter, here we use the internal approximation algorithm, proposed by O.Pantz [2], that is able to directly manage the cases of thin structures and self-contact. Moreover, the dual approach used in this algorithm allows to add the contact problem in the partitioned scheme without modifying any part of the structure solver. The proposed algorithm is finally applied to the simulation of real aortic valves (Figure 1) and some numerical results are presented (Figures 2 and 3).

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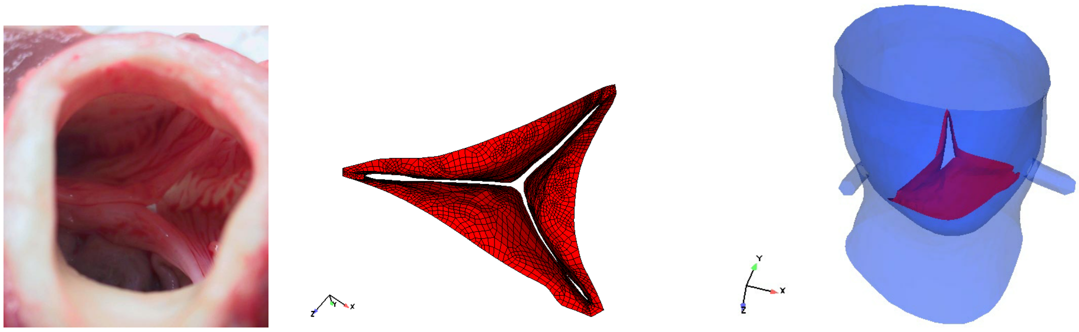

Figure 1: From left to right: view of the three semilunar leaflets from the arterial lumen of the aortic orifice (from [3]); mesh of the three semilunar leaflets; fluid and structure computational domains (aorta and aortic valves).

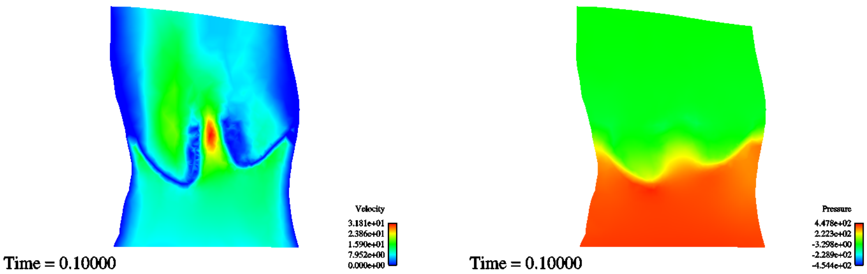

Figure 2: Velocity and pressure fields in the fluid domain.

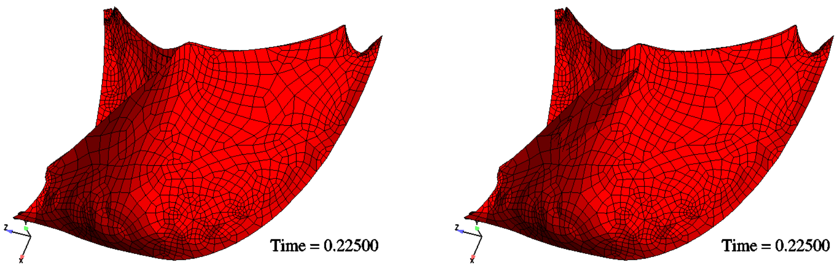

Figure 3: Closure of the aortic valves with (left) and without (right) the use of the contact algorithm. In the right one it could be observed an interpenetration of different parts of the valves mesh, absent in the left one.