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STABILITY ISSUES OF IMPLICIT COUPLING METHODS FOR PARTITIONED SOLVERS IN BIOMECHANICAL APPLICATIONS

***Jan A. Vierendeels[1], J. Degroote[1], R. Haelterman[2] and P. Bruggeman[3]**

[1] Ghent University,
Department of Flow, Heat and Combustion Mechanics
St.-Pietersnieuwstraat 41
B-9000 Gent, Belgium
Jan.Vierendeels@UGent.be,
Joris.Degroote@UGent.be
www.FloHeaCom.UGent.be

[2] Royal Military Academy
Renaissancelaan 30
B-1000 Brussel, Belgium
Robby.Haelterman@rma.ac.be
www.rma.ac.be

[3] Ghent University
Department of Applied Physics
Rozier 44
B-9000 Gent, Belgium
Peter.Bruggeman@UGent.be
www.appliedphysics.ugent.be

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ABSTRACT

A review is given on stability issues for fluid-structure interaction (FSI) problems we encountered and studied in the last decade. The applications are all in the biomechanical field. These are representative for more general strongly coupled problems with incompressible fluids and flexible structures. Only implicit coupling is studied with partitioned solvers.

The first topic that will be addressed is the stabilisation of a fluid-structure interaction coupling method applied to FSI in elastic tubes by the introduction of artificial compressibility in pseudo-time in the flow solver [1,2]. Between each coupling iteration a pseudo-time step is performed. After convergence of the coupling iterations the obtained solution fulfills the incompressibility constraint on the fluid. Fourier analysis shows that the introduction of artificial compressibility stabilizes the coupling method. Without the introduction of artificial compressibility the method is equivalent with a standard fixed-point coupling method during the coupling iterations of a time step. Fourier analysis shows that in that case the method becomes more unstable when the time step is reduced or when the structure becomes more flexible or when the length of the tube increases. Such behaviour is also explained in [5] and [8].

The next topic that will be addressed is FSI of a stiff prosthetic heart valve with a loose hinge [3,4]. The influence of the density of the fluid and the solid, the influence of the geometry (different behaviour for valves which are almost closed than for valves which are open) and the influence of the time step on the stability of the coupling method is analyzed. Also the influence of the use of different time discretization schemes for the fluid problem and the solid problem is analyzed. It is shown that if the FSI interaction is very strong (presence of very small gaps, valves nearly closed) that even if coupling is obtained (same solution as monolythic) that wiggles appear when angular acceleration

is plotted as a function of time. This behaviour depends strongly on the choice of the time integration schemes in the flow and the structural solver. Only when equal time discretization schemes are used for the fluid and the solid, these wiggles disappeared completely. This corresponds with the analysis. In case when wiggles in the angular acceleration are present, also the moments on the valve and the pressure load on the valve shows this behaviour. Therefore stress analysis on the valve can not be done with such solutions. However these wiggles are hardly seen in the velocity and displacement field.

Finally, the performance and stability of the newly developed coupling method based on reduced order models is discussed shortly [6,7]. This method has been applied on flexible heart valves, flow in an artery and flow in the heart itself. The method has also been succesfully applied to gas-liquid interface problems calculated with the ALE (Arbitrary Lagrangean-Eulerean) method. More details about this method and performance issues are given in the Eccomas 2008 paper authored by J. Degroote where this method is also compared with other methods, e.g. Aitken's coupling method.

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