TEMPORAL STABILITY OF THE FLOW SIMULATION IN A FLEXIBLE ARTERY USING DIFFERENT TIME INTEGRATION SCHEMES AND TIME STEP SIZES FOR THE FLUID AND THE STRUCTURE

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1 Background

Partitioned fluid-structure interaction (FSI) simulations often use different time integration schemes to discretize the different sub-problems. As each time integration method is characterized by its accuracy, stability and numerical dissipation, this approach allows the flow and the structural equations to be solved with schemes that are particularly suited to solve each individual sub-problem. Furthermore, FSI problems sometimes require different time scales in the different sub-problems (Δt_{fluid} versus $\Delta t_{\text{structure}}$). One example are FSI problems involving large-scale flow structures like vortex shedding or flow separation, which might occur in the aorta, e.g. downstream a prosthetic valve. In such cases large eddy simulations (LES) are required and small time steps are needed to resolve the flow field in time.

However, according to our experience with FSI simulations of the aortic arch, simulations coupling different time integration schemes and time step sizes can encounter stability problems. The stability issues that emerged from these simulations were the motivation to perform a stability analysis.

2 Methods and materials

First, an analytical study is presented in which the temporal stability of the one-dimensional unsteady flow in a straight, flexible artery is studied. In this analysis the time step size of one sub-domain is considered to be *k* times the time step size of the other sub-domain with *k* a positive integer. For $k > 1$ 'subcycling' is applied, performing smaller time steps in one of the sub-domains. The governing equations are discretized in space and time and subsequently linearized. The backward Euler scheme (BE) is used for the time discretization of the flow equations. For the temporal discretization of the structure two schemes are used: (1) the backward Euler scheme and (2) the operator defined by Hilber, Hughes and Taylor (HHT), in which the numerical damping is controlled by a single parameter α [1].

The influence of some numerical and physiological parameters on the stability and the damping of the spurious modes is studied. Particular attention is paid to the effect of the fluid to solid time step size ratio and the numerical dissipation of the HHT time integrator.

The analytical results are verified by a numerical study in which the propagation of a sinusoidal flow wave in a straight artery is simulated using nonlinear two-dimensional axisymmetric FSI simulations.

3 Results

According to this analysis, the combination of the BE and HHT scheme is stable for parameter values that approximate the flow in an artery and a ratio of Δt_{fluid} to $\Delta t_{\text{structure}}$ smaller than or equal to one. The simulation of a wave with a small wave length will experience a better damping of the spurious modes than the simulation of a wave with a large wave length. Only for large wave lengths, the damping of the spurious modes can be improved by increasing the numerical damping α.

The higher the ratio of solid to fluid density, the better the spurious modes are damped. An increase in radius and wall thickness of the artery have a positive effect on the damping of the spurious modes.

These conclusions are confirmed by the results of the numerical FSI simulations.

References

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