Numerical and analytical investigation of subcycling in the flow problem of a strongly-coupled partitioned fluid-structure interaction simulation

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ABSTRACT

Fluid-structure interaction (FSI) simulations are often used to quantify the frequency, damping constant and amplitude of the vibration of equipment such as piping and heat exchangers. Partitioned FSI simulations require two separate solvers – one for the flow and one for the structural equations – and a coupling code. Typically, the time step is the same in both solvers, but this causes long computational times when the time step is restricted due to stability requirements of only one solver. In that case, a more efficient approach is to use so-called subcycling with a different time step in the solvers. This reduces the required communication between the solvers and decreases the number of evaluations in one of the solvers, effectively lowering the required CPU time. In most applications, the most stringent time step criterion is imposed by the stability requirements of the flow solver, for example because of the applied time discretization schemes or due to the presence of waves. Consequently, only subcycling in the flow solver – so with a smaller time step in the flow solver compared to the structural solver – will be analyzed. In general, partitioned FSI calculations are divided in two subcategories: explicit and implicit coupling. In explicit coupling, the flow and structural equations are solved only once per time step, whereas implicit (or strong) coupling implies the use of coupling iterations between the flow solver and the structural solver. In this paper, only implicit coupling is considered, as a large number of stability analyses on subcycling in explicit coupling can be found in literature.

The research presented here is split into two parts: an analytical study and a numerical computation of the one-dimensional flow in an elastic cylindrical tube. Firstly, a monolithic analytical FSI calculation is performed, followed by a Fourier stability analysis. This allows to verify the stability of the solution by considering the eigenvalues of the problem as a function of perturbation wavenumber. The conclusions drawn from the analytical study are subsequently verified in a partitioned numerical FSI simulation, coupling the flow solver Fluent with the structural solver Abaqus. The coupling is achieved using an interface quasi-Newton method with an approximation of the inverse of the Jacobian (IQN-ILS), implemented in the in-house code Tango. To the best of the authors' knowledge, it is the first time a stability analysis is performed on a strongly-coupled partitioned FSI simulation with subcycling.

The research shows that a stable solution is attained for significant subcycling in the flow problem: the results indicate that the solution remains temporally stable even if the time step in the flow solver is only one tenth of the structural time step. However, some (temporally stable) oscillations in the resulting pressure profile on the pipe wall arise when the time discretization schemes applied in the flow and structural solvers are different. These oscillations do not persist when the same time discretization scheme is applied.