

# Numerical Investigations of a Partitioned FSI Algorithm for Tetra Pak's Filling Tube

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*Fluid-structure interaction is a very hard problem to handle numerically. This thesis finds out why simulations of a water filled tube tend to crash and what can be done to keep them stable. It turns out that the main cause is the added mass effect, and a model problem is used to find theoretically stable parameters.*

Tetra Pak is one of the world's largest producers of food packaging technology and one of their main innovations is the *filling tube*. This is a paper tube filled with liquid which is clamped under the surface in order to produce individual packages. The company wants to simulate its behaviour in order to better understand the whole process, but there are practical difficulties in doing the calculations. The simulations tend to become unstable and crash. To handle this problem the engineers have introduced two forms of numerical damping:  $\beta$ -damping acting on the paper walls and grid flux under-relaxation which makes the fluid ignore some of the effects of the moving walls. Their question was if these parameters affect the solution and if there are better ways to keep the simulations stable.

It turned out that  $\beta$ -damping damped out the solution a lot and if this was set high enough you would miss the whole range of interesting behaviour. Therefore  $\beta$  should be decreased or even removed. The grid flux under-relaxation changed the solution too, but in a much more erratic way. Using 0.7, as was the case in most of the simulations, caused the solution to miss a peak at the end of a load cycle while this was visible for both 1 and 0.3! It seems there is no way of knowing what goes missing for a certain grid flux, unlike  $\beta$  which successively damps out the solution.

The way these simulations are performed is by solving the fluid flow, taking the pressure on the wall and inputting this into the solid solver, which will yield a displacement. Then the new displacement is imported into the fluid solver, which calculates a new flow field, and so on until nothing changes any more. Then both solvers take a time step and start this iterative process again. There is an option to under-relax the displacements by letting the fluid solver get a blend of the newly calculated displacement and the last displacement, where a coefficient  $\omega$  determines how much of the new displacement is added. Setting  $\omega$  low will make the displacements take very small steps which helps the algorithm keep stable but may increase computation times.

When the wall moves it displaces some fluid, which will cause reaction forces on the wall. This is called the *added mass effect* and plays an important role in the stability of the algorithm. It turns out that looking at the time integration scheme of the wall and describing the imported pressure by the added mass effect one can find out how low you need to set  $\omega$  for the algorithm to be stable. This criterion takes geometry, materials, time step and  $\beta$  damping into account. Surprisingly the stability gets worse for smaller time steps, which is completely the opposite of the usual situation in many cases where an engineer typically decreases the time steps to *improve* stability. It was also found by considering a model problem that long tubes, weak structures and heavy fluids make stability worse. Just as experience indicates,  $\beta$  damping helps a lot with stability but unfortunately at the cost of accuracy.

This criterion was validated against simulations of a simplified tube model, and despite having made a lot of assumptions in the model problem the correspondence was good. Now the engineers know why the simulations crash, what can be done to help keep them stable and what parameter choices are reasonable.

In conclusion  $\beta$  should be decreased, grid flux under-relaxation not used at all and if there are problems with stability, increase the time step or decrease the displacement under-relaxation  $\omega$ .