# Interaction between a submarine and a far-field underwater explosion with a transient iterative FEM-BEM coupling

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**Abstract**: This work contributes to the simulation of the fluid-structure interaction (FSI) undergone by submarines subjected to a far-field underwater explosion. In such events, two physical phenomena occur. After a few milliseconds, an acoustic shock wave (fast excitation, linear acoustic fluid) first reaches the ship before a subsequent, slower, fluid motion also affects the ship over a longer time scale. These two phenomena can be studied in a decorrelated way [1]. Numerical methods for solving the two stages of the FSI problem were proposed in [2] and applied to complex and realistic geometries (with several millions of degrees of freedom on the ship surface for the first stage). Regarding the first stage, the original goal of [2] was to implement the coupling of time-domain FEM for the ship and a "Z-BEM" approach that combines a fast boundary element method (BEM) implemented in the Laplace domain with the convolution quadrature method (CQM) for the discrete-time response of the whole fluid domain. The latter method was accelerated with a Fast Multipole Method and the use of a high frequency approximation, the BEM solutions at complex frequencies used by the CQM being computed in parallel [3]. At the time, a heuristic iterative approach for coupling the FEM and the Z-BEM failed to converge, however. The Z-BEM was proved very effective on large and realistic models [3], but could only be used at the initial stage of the complete FSI analysis in [2]; then, the FEM was also used for a surrounding fluid region. While workable, this treatment entailed significant meshing difficulties.

In the present follow-up work, we revisit the issue of coupling the transient Z-BEM (for the fluid) and the transient FEM (for the ship) towards solving the first (fast) stage of the FSI computation, in order to be able to use only the BEM for the (unbounded) fluid domain. To replace the previously-tried Neumann-Neumann (NN) coupling iterations (which failed to converge), we propose an iterative coupling scheme based on Robin-Robin (RR) iterations. By applying function analysis arguments to the continuous acoustic-elastodynamic FSI problem as well as the auxiliary acoustic and elastodynamic problems, we both (i) explain why the previous NN iterations applied to the transient FSI problem had to diverge, and (ii) prove that our proposed RR iterations are convergent for the FSI problem. We demonstrate our convergent coupled Z-BEM/FEM method on several examples, and highlight treatments allowing to accelereate the computation: reuse of compressed BEM operators at each coupling iteration, and convergence acceleration methods that reduce the number of coupling iterations (Aitken method, relaxation). Finally, the efficiency of this method to accurately simulate realistic problems will be illustrated with examples from the naval engineering industry.

**Keywords**: Fluid-structure interaction; underwater explosion; shock wave; finite elements; boundary element method; FEM-BEM coupling.

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