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Numerical Simulation of Water Impact in 3D by LVOF

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ABSTRACT

Based on our highly efficient Navier-Stokes solver, LVOF (Li, et al., 2004, 2007), we present some results for water entry and exit in a 3D numerical wave tank, by implementing our design of a mass-force coupling scheme for water impact (Li, et al., 2007a). LVOF is constructed by a novel VOF finite volume cut-cells approach that incorporates surface tension, coupled with a dynamic subgrid-scale model.

Our mass-force coupling model in theory represents the coupling of a moving body on the flow, which is realized through introducing the internal source function. Importantly, a solid body is treated as a fluid, especially the solid-liquid phase front is captured over a fixed Cartesian grid without smearing the information at the particle-fluid interface.

Grid refinement studies are performed for test problems involving the wedge entry and exit. In addition, issue about the convergence performance is addressed under the prescribed entry velocity. Very encouragingly, the results agree with measurements available. It is demonstrated that most of typical features in complex flow patterns can be captured in waves caused by impact, by using LVOF.

KEY WORDS: Water entry/exit problems, LVOF, 3D, slamming.

INTRODUCTION

Fluid-body coupling is the particular problems of interest, especially when a solid body is slamming into water, as such slamming can give rise to serious damages to structures. Physically, the major process involved is subjected to splashing and breaking waves, characterized by violent free-surface deformation, implying strong nonlinear features in the localized turbulent flow.

Theoretically, the relevant study mainly involves numerical modelling of moving boundary problems associated with the free surface and the fluid-particle interface as well. Until recently, various theory models are applied for case studies related to slamming problems. Within the framework of the Navier-Stokes equations, probably most of the study in this area is restricted to 2D, for example, by using a SPH method (Oger et al., 2006) and a CIP approach (Hu and Kashiwagi, 2004), including the work of Heinrich (1992) with a VOF scheme. Ideally, the simulations in 3D start from rest as one kind of the most general situations in a numerical wave tank, which obviously differ from the previous studies (Li, 2003) and (Fringer and Street, 2003). In the former case, the steady-state solution on the 3D coarse grid is assigned as an initial guess for the fine solution; on the other hand, the calculated results in 2D are interpolated onto the 3D domain for the latter. In this sense, white noise (i.e. an initial disturbance) is not necessary to impose on modelling of water impact, excepting the state of a moving body prescribed.

Similar to flows around ships, early attempts are to specify inflow boundary at the bottom of the domain, by assigning the desired water-entry velocity in 3D (Muzaferija et al., 2000) with a two-fluid Navier-Stokes solver and in 2D (Clarke and Tveitnes) with Fluent 4© (Fluent Inc.). Computationally, the moving body is enforced to hold stationary, as opposed to Lagrangian strategies. In the Lagrangian context, problems of the forced motions can be resolved by handling a full fluid-body interactions, based on force equilibrium and energy conservation, as the coupling between two phases is restored in a more coherent manner (Kleefsman, et al., 2005, Oger, et al., 2006). Interestingly, the net body force is introduced to the governing equations, which accounts for the effects of a moving body without any additional complications to extend to 3D (Liu et al., 2005).

Given the prescribed velocity of a moving body, the major concern of this paper is on modelling of water impact in 3D, according to three types of different applications of interest, e.g. the entry and exit of a body, slamming and landslide-generated water