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# Numerical Simulation of 3D Free-Surface Flows by Using CIP-based and FV-based Methods

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## ABSTRACT

In this paper, three-dimensional free-surface flows are simulated by using two different numerical methods, CIP(constrained interpolation profile)-based and FV(finite volume)-based methods. In the CIP-based method, the Euler equation is solved on stationary staggered Cartesian grids by a finite difference method, and an immersed boundary technique is applied to deal with wave-body interactions. In the FV–based method, the governing equations are solved by applying collocated finite volume discretization, and body-fitted meshes are used. Free-surface boundary is considered as the interface of multi-phase flow with air and water, and a volume-of-fluid (VOF) approach is applied to trace free surface. Among many variations of VOF-type method, the tangent of hyperbola for interface capturing (THINC) and compressive interface capturing scheme for arbitrary meshes (CICSAM) techniques are used in the CIP-base method and FV-based method, respectively. Numerical simulations have been carried out for dam-breaking and wave-body interaction problems. The computational results of the two methods are compared with experimental data and their differences are observed.

KEY WORDS: Wave-body interaction; CIP; FVM; VOF; THINC; CICSAM.

## INTRODUCTION

Wave-body interaction problems are important for the design of ships and offshore structures. Potential-based codes give reasonable results for engineering purpose. However, they have some limitations to simulate strongly nonlinear wave-body interaction flows. Among alternative approaches, direct numerical methods based on the Navier-Stokes or Euler equations are getting popular, thanks to the dramatic increase of computational resources. Yang and Löehner (2006) also showed highly nonlinear wave-body interaction simulations such as slamming and green water using VOF, FEM, and suggested efficient extrapolation algorithm. Hu et al. (2008) showed some three-dimensional computations of strongly nonlinear wave-ship interaction problems by using CIP method. Monroy et al. (2009) presented the Reynolds Averaged Navier-Stokes (RANS) simulations of ship motions in regular and irregular head seas, cooperating with potential-based incident waves.

The major difficulty in the numerical simulation of highly nonlinear wave-body problems is that the topology of free-surface boundary can be largely distorted, fragmented and merged. The volume-of-fluid method is one of the most popular schemes for studying two-phase flow problems with free surface. In the VOF method, computations can be performed on a fixed grid system without interface tracking procedure, and the interface is captured as a part of solutions with ensuring mass conservation. Among many variations of VOF method, CICSAM, which is firstly suggested by Ubbink and Issa (1999), is adopted for the FV-based method, because their method is flexible enough to apply unstructured grid system and to retain appropriately the transitional region between two fluids during the long-time simulations. Recently, Xiao et al. (2005) developed the tangent of hyperbola for interface capturing (THINC) scheme, showing good performance compared with the other interface capturing methods even very simple algorithm. This method adapted for the CIP-based method.

In this paper, mathematical model is based on the three-dimensional unsteady incompressible Navier-Stokes equation which is solved two different numerical methods, CIP and FV based methods. In the CIP-based method, the Euler equation is solved on a stationary staggered Cartesian grid by a finite difference method, and the immersed boundary technique is applied to deal with wave-body interactions. In the FV–based method, the governing equations are solved by using collocated finite volume discretization, and body-fitted meshes are used. To compare and verify the accuracy of developed methods numerical simulations have been carried out for two problems: a dam-breaking problem with an obstacle, and wave-body interaction for a truncated circular cylinder.

## NUMERICAL METHODS I: CIP-Based Method

### Field Equation Solver

The CIP method was developed by Takewaki (1987) in order to reduce numerical diffusion. The key idea of the CIP method is to approximate both a physical parameter, say *f*, and its spatial derivatives as cubic polynomials at grid points for the interpolation of parameters inside cell. Once the interpolation function is constructed, a semi-Lagrangian procedure is applied for time evolution as follows: