Validation Methods and Benchmark Tests for a 2-D CIP Method
Applied to Marine Hydrodynamics

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ABSTRACT
In this paper, validation and verification of a 2-D Constrained Interpolation Profile (CIP) method is presented. Convergence and conservation of continuity and energy are checked. Benchmark tests are presented where analytical solutions, good results from other numerical methods and experiments are available. Examples are shear driven cavity flow, viscous damping of linear sloshing modes, moderate cavitation flow, and simple numerical wave tank.

KEY WORDS: Marine hydrodynamics; CFD; CIP method; Validation; Numerical wave tank.

INTRODUCTION
In recent years, there has been an increase in the research effort on new CFD methods applied to marine hydrodynamics. Methods such as Level Set, Smoothed Particle Hydrodynamics, CIP and Volume of Fluid are now popular in this field. New variants and hybrid methods specialized for specific problems are constantly being developed. Such codes are frequently applied to violent nonlinear problems, simply because other numerical methods, and even experiments, may not be well suited for this type of problems. However, the CFD methods must also handle simpler cases in order for us to have confidence in the more complicated simulations. Many of the these methods are known from other fields within fluid dynamics, and validation and benchmark tests are often taken from these fields. There is a need for the CFD community within marine hydrodynamics to develop validation methods and benchmark tests especially suited for this field.

In (ITTC 1990), guidelines are given for the validation of CFD codes. It is important to note the difference between verification and validation. The verification process is defined as checking that the computer program is an adequate representation of the physical reality. The validation process is thus a broader activity including verification. In this paper, the validation process of a CIP code is presented. The CIP code under development aims at computing the forces on an offshore platform exposed to extreme waves hitting the platform deck. The test cases and benchmark tests applied are chosen because they focus on important issues towards this goal. Important in the process is checking stability, consistency and convergence of the code. For nonlinear codes, it is difficult to perform e.g. stability analysis directly. Performing temporal and spatial convergence tests are important, and are performed for this code for all of the presented test cases. The ITTC guidelines also underline the importance of describing and evaluating the time evolution and discretization schemes, solution techniques and the boundary and initial conditions. In the next section, the CIP method is briefly described and the issues above discussed.

THE CIP METHOD
The CIP method is a high-order upwind scheme for solving the Navier-Stokes equations, see Yabe, Xiao and Utsumi (2000). The CIP method was introduced some 20 years ago. The method for hydrodynamic problems using a pressure-based algorithm is called the CIP combined and unified procedure (CCUP), see Hu and Kashiwagi 2004. Their 2-D incompressible CCUP version of the CIP method is used for the simulations presented in this paper. The name “Constrained Interpolation Profile” actually refers to the method for solving the advection part of the Navier-Stokes equations. Sub-cell resolution is obtained by using both the advected function and its spatial derivatives at the grid points to estimate the function inside the cell. The advection equation of a function $G$ is written as:

$$\frac{\partial G}{\partial t} + u_i \frac{\partial G}{\partial x_i} = 0$$  \hspace{1cm} (1)

Here, $u_i$ is the velocity field. By differentiating Eq. 1 with respect to the spatial coordinates, we obtain the transport equations of the spatial derivatives of $G$, $H_i = \frac{\partial G}{\partial x_i}$.

$$\frac{\partial H_i}{\partial t} + u_j \frac{\partial H_j}{\partial x_i} = -H_j \frac{\partial u_j}{\partial x_i}$$  \hspace{1cm} (2)

The $x$- and $y$-directions are denoted by $i, j=1,2$, respectively. Estimates $G^\ast$ and $H_i^\ast$ of the left-hand sides of Eqs. 1 and 2 are found using a semi-Lagrangian approach.