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# Time-domain Simulation of Large-amplitude Ship Roll Motions by a Chimera RANS Method

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## ABSTRACT

**A Reynolds-Averaged Navier-Stokes (RANS) numerical method has been employed in conjunction with a chimera domain decomposition approach for time-domain simulation of large-amplitude ship roll motions. For the simulation of arbitrary roll motions, it is convenient to construct body-fitted numerical grids for the ship and ambient flow domain separately. The ship grid block is allowed to roll with respect to its center of rotation under either forced or free roll conditions. The roll moments are computed at every time-step by a direct integration of the hull surface pressure and shear stresses obtained from the chimera RANS method. The simulations for prescribed roll motions of a full-scale motor vessel clearly show that the bilge keels at mid-ship produced large roll damping but generated very small waves. On the other hand, the ship skag acted as a wavemaker during the roll motion and produced large wakes in the stern region. Time-domain simulations were also performed for a free-floating pontoon barge in free decay motions and under large-amplitude incident waves. The simulation results successfully predicted the roll resonance when the incident wave coincides with the natural roll period (free decay period) of the barge.**

## INTRODUCTION

The roll motions of ships and barges in incident waves are one of the primary concerns in naval architecture and ocean engineering. For small-amplitude wave and body motions, linear or perturbation theories are often used in frequency domain to predict the responses. During the past decade, several numerical and experimental studies have been conducted for roll motions of floating bodies. Time-domain, fully nonlinear simulations of parametric roll motions were studied by Cointe et al. (1990) and Tanizawa and Naito (1997, 1998), among others. However, most of the numerical studies used potential flow methods with the artificial damping terms added to dynamic and kinematic free-surface boundary conditions. More recently, Yeung, Liao and Roddier (1998) and Yeung and Liao (1999) developed a free-surface random-vortex method for the simulation of floating cylinders in viscous fluid. Kang, Chen and Huang (1998) and Chen, Kang and Huang (1998) employed a chimera domain decomposition approach for the simulation of viscous, nonlinear, free-surface flows induced by 2-dimensional ship sway, heave, and roll motions. In this study, the chimera RANS method of Chen and Chen (1998) and Chen et al. (2000) has been generalized for large-amplitude roll simulations around practical ship and barge configurations. Calculations were first performed for a motor vessel under prescribed roll motions. The method was then extended for free decay roll simulation of a barge in calm water. Finally, the method was employed for time-domain simulation of a free-floating barge subject to large-amplitude incident waves. A parametric study was performed to examine the resonance effects between the roll-motion responses and incident wave conditions.

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KEY WORDS: Ship roll motion, free decay simulation, incident waves, turbulent flow, Navier-Stokes equations, chimera domain decomposition.

## NUMERICAL METHOD

The present study is concerned with the roll motion of 2- and 3-D ships with or without the presence of ambient waves. Simulations were first performed for prescribed roll motions in calm water to evaluate the general performance of the numerical method. The method was then extended to simulate free-floating bodies in ambient waves under various incident wave conditions.

For viscous flow simulations, the chimera RANS method of Chen and Chen (1998) and Chen et al. (2000) has been employed for the accurate resolution of the viscous free-surface flow induced by ship roll motions. The method solves the nondimensional Reynolds-Averaged Navier-Stokes equations for incompressible flow in orthogonal curvilinear coordinates $(x^i, t)$:

$$U^i_{,i} = 0 \tag{1}$$

$$\frac{\partial U^i}{\partial t} + U^j U^i_{,j} + \overline{u^i u^j}_{,j} + g^{ij} p_{,j} - \frac{1}{\mathrm{Re}} g^{jk} U^i_{,jk} = 0 \tag{2}$$

where $U^i$ and $u^i$ represent the mean and fluctuating velocity components, and $g^{ij}$ is the conjugate metric tensor. $t$ is time, $p$ is pressure, and $\mathrm{Re} = U_o L/\nu$ is the Reynolds number based on a characteristic length $L$, a reference velocity $U_o$, and the kinematic viscosity $\nu$. Eqs. 1 and 2 represent the continuity and mean momentum equations, respectively. The equations are written in tensor notation with the subscripts, $, j$ and $, jk$, representing the covariant derivatives. In this study, the 2-layer turbulence model