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Numerical Simulation of Transient Flows Induced by a Berthing Ship

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ABSTRACT

A chimera Reynolds-Averaged Navier-Stokes (RANS) method has been developed for time-domain simulation of transient flow induced by a ship approaching a berthing structure. The method solves the mean flow and turbulence quantities on embedded, overlapped or matched grids. The unsteady RANS equations were formulated in an earth-fixed reference frame and transformed into general curvilinear, moving coordinate systems. A chimera domain decomposition technique has been employed to accommodate the relative motion between different grid blocks. Kinematic and dynamic free surface boundary conditions were applied on the exact free surface to ensure accurate prediction of the water cushion between the ship and the berthing structure. Calculations have been performed for a two-dimensional ship hull form in lateral motion to demonstrate the feasibility of the chimera RANS approach for time-domain simulation of the hydrodynamic coupling between the ship and berthing structure. The numerical solutions successfully captured many important features of the transient flow around a berthing ship, including the underkeel flow acceleration, wake flow separation, and water cushion between the ship and harbor quaywall.

INTRODUCTION

Berthing damage can result in substantial economic and operational penalties. Even in a well-executed berthing, a large ship possesses enormous kinetic energy that could seriously damage the berthing structure as well as the ship itself. Fender systems are provided at a berth to absorb the kinetic energy of the berthing ship and to mitigate impact forces. The amount of the energy to be absorbed and the maximum impact force are the prevailing criteria for fender system design. However, due to the complexity of the berthing process, which involves structural and fluid coupling among the ship, fender system and surrounding water, a reliable and accurate assessment system for computing berthing energy has yet to be developed. Currently, the most commonly used fender system design methodology accounts for the influence of the ambient water with a simple constant coefficient (Lee et al., 1975; Plotkin, 1977; Keuning and Beukelman, 1979; Fontijn, 1980, 1988). Fender designs based on this approach experience a high rate of failure due to underdesign, or they are more costly than necessary through overdesign. In order to improve the fender system design, it is necessary to develop an accurate model for the simulation of ship and fluid interactions during typical ship approaches to a berthing structure. The model must be able to include the effects of the fluid viscosity, underkeel clearance and free surface variations for accurate prediction of the hydrodynamic coupling between the vessel and the berthing structure.

Recently, Hubbard and Chen (1994, 1995) developed a chimera RANS method for steady and unsteady incompressible flows. The method solves the mean flow and turbulence quantities on structured multiblock grids using a chimera domain decomposition approach (Benek et al., 1985, 1987; Suhs and Tramel, 1991). The chimera method is used to connect embedded or patched grids by interpolating information across the block boundaries. This technique has been found to be very effective in simplifying the grid generation for complex configurations and in areas of high gradients. Multiblock grids can be generated without regard to the smoothness with which blocks fit together, and the fine resolution required near a body needs not extend into the far field. Thus, grid generation is greatly simplified, and accurate solutions can be obtained with few points. For problems involving relative motion between different subdomains such as the berthing problems considered here, the chimera method can also be extended to allow movement of the grids in unsteady flow analysis. This provides a very effective and flexible treatment of complex three-dimensional geometry and flow conditions in multiply connected flow domains.

In order to provide accurate resolution of the complex flow around a berthing ship, the chimera RANS method of Hubbard and Chen (1994, 1995) has been extended with several major improvements in both the unsteady capability and adaptive generation of time-dependent chimera grids. Initial study was focused on the time-domain simulation of a ship approaching a berth with prescribed translational motion to demonstrate the feasibility of the chimera RANS approach. This is an important step in the development of a more accurate computer model for the prediction of the complete ship-berthing problem.

Calculations have been performed for a two-dimensional berthing ship in a fully sheltered harbor under different flow conditions. The effects of underkeel clearance and water cushion between the ship and the harbor quaywall have been investigated to facilitate a detailed assessment of the proposed chimera RANS solution technique. The ultimate goal of the present research is to develop an unsteady Reynolds-Averaged Navier-Stokes method for time-domain simulation of transient flow induced by a ship approaching a berthing structure with various combinations of translational, rotational and/or roll motions.

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KEY WORDS: Chimera domain decomposition, moving grids, turbulent flows, unsteady flows, nonlinear waves, berthing ships, underkeel clearance, water cushion.