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Comparison of potential and viscous methods for the nonlinear ship wave problem

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ABSTRACT: *The two different numerical approaches for solving the nonlinear ship wave problem are discussed in the present paper. One is based on a panel method, which neglects the viscous effects. The other is based on a finite volume method, which take into account the viscous effects by solving RANS equations. Focus is laid upon on the advantages and disadvantages of two methods. The developed methods are applied to calculating the flow around Series 60 hull to validate the performance of the present nonlinear methods. Although the two methods employ quite different numerical approaches, the calculated wave patterns from both methods show good agreements with the experiments. However the potential method simu-lates the global wave pattern accurately, while the viscous method shows better performance for the local wave prediction near a ship.*

KEY WORDS: Panel method; Finite volume method; Free surface flow; Wave pattern.

INTRODUCTION

The steady ship wave problems have significant importance in marine hydrodynamics. The wave patterns generated by an advancing ship have large influence on the total resistance of a ship. In addition the wave patterns are very sensitive to the details of hull form design and are easily affected by relatively small modifications. Consequently, the capability to predict the wave pattern accurately for a given hull form is an important asset in the initial stage of hull form design. Therefore the effects of a free surface must be taken into account in the relevant methods for solving ship wave problems. The primary difficulties of ship wave problems arise from the nonlinear behavior of the free surface condition, i.e. the boundary condition must be applied on the wavy free surface, which is not known a priori.

The standard approach to the nonlinear ship wave problem may be divided two distinct methods; either the inviscid flow method or viscous flow method. Though the inviscid flow methods don't consider the interaction between the viscous and the wavemaking components, those methods are widely used in marine hydrodynamics because of their robustness and computational efficiency. The inviscid flow methods may be categorized in two general groups, i.e. the panel/boundary element methods (Raven, 1996; Janson, 1997; Kim et al., 1998) and the field methods (Farmer et al., 1994) that solve the Euler equation. The formers have been proven to be the most effective for obtaining fast solutions of nonlinear ship wave problems. At present, panel methods already have reached the maturity for the design tool. And from the numerical point of view, the field methods that solve the discretized Euler equations have inherently the same numerical difficulties of the following viscous flow methods. As a candidate for the inviscid flow calculation the panel/boundary element methods are believed to be better than the field methods with regards to the applicability and computational efficiency of the solution method. Therefore the field methods solving Euler equations are not further considered here.

The viscous flow methods can be divided into two categories based upon the coordinate system in which the governing equations are solved: interface-capturing methods and interface-tracking methods. The interface-capturing methods such as the volume of fluid approach (Schumann, 1998) make use of an inertial coordinate system. In all these approaches a grid fixed in time is used and the free surface is allowed to move between grid points. Thus, tracking the free surface and imposing the boundary conditions on it are not trivial in these approaches. On the other hand, the interface-tracking method, which is also called moving grid approach, makes use of a non-inertial coordinate system and the free surface coincides with a grid surface exactly through the calculations. Thus, imposing the boundary conditions on the free surface as well as tracking the free surface in time is straightforward. However, these approaches involve grid regeneration at every iteration step, which may not be possible for all cases. If the breaking and overturning waves, which are not modeled in panel

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methods either, are of no primary interest, the interface-tracking methods are more accurate than the interface-capturing methods with regards to predicting the ship-generated wave patterns. The interface-tracking methods (Muzaferija and Peric, 1997) are therefore adopted in the present work.

Another issue remains for steady nonlinear ship wave problem, i.e. whether a steady-iterative or a time-dependent solution method is to be adopted in the numerical methods for handling the free surface flow. Firstly, the time-dependent solution methods have the advantage with regards to applicability to truly unsteady free surface problems. But it should be pointed out that the steady solution is of primary interest for the nonlinear ship wave problem. From this point of view the discussion will be given below.

For the time-dependent approaches, the simple and natural formulations of the time-stepping procedure are possible. Most time-dependent approaches reach the steady state by starting from the rest and accelerating a ship to its final speed. If the time-dependent solution methods retain the time accuracy in each time steps, much additional flow information besides the steady solution can be obtained. Another advantage of the time-dependent approach is the fact that the initial boundary conditions can be easily given, especially for the viscous methods. This is why most viscous methods for a nonlinear ship wave problem adopt the time-dependent approach.

As opposed to these advantages, the computing demands of relevant methods are significantly excessive before a steady solution is reached. Another difficulty is present in the time-dependent approach, i.e. the non-reflective outer boundary conditions have to be specified. Otherwise the reflective waves will spoil the solution and delay the convergence to a steady state. Some damping zone techniques (Hino, 1994; Hinatsu, 1992), which are adopted in the present viscous method, require the more computing demands due to the additional computational domain for the damping zone.

If the steady solution is of primary interest, steady-iterative solution methods are believed to be more efficient. In the steady-iterative solution methods, the steady solution is found in an iterative procedure starting from the initial guess of the solution. Especially, for the potential methods the good initial guess is available in order to start the iterative procedure. There have been various linear solutions (Raven, 1988) approximating the nonlinear ship wave problem. Following the discussion of Raven (1996), the steady-iterative solution method is adopted for the potential method in the present study.

As mentioned previously, the wave pattern generated by an advancing ship have a dominant effect on the flow around her. In 1994, there has been a workshop (Kodama, 1994) for comparison of the numerical methods that can deal with a free surface flow. In this workshop, Series 60 hull form was used for comparative computations. The numerical results with various potential and viscous methods are collected and compared with the experiments. Recently a number of numerical methods for the nonlinear ship wave problem have been developed and updated since the previous workshop. The present paper is initiated from the questions that how accurately the state-of-the art numerical methods at present can predict the wave pattern generated by a ship and how much the viscosity of the fluid has influence on the stern wave. Therefore the present paper lay a primary emphasis on the capability for predicting the wave patterns around a ship in the potential and viscous methods. The evaluation and validation of both methods will be performed by the detailed comparison at the various longitudinal and transverse cuts with the extensive experimental data by Toda et al. (1991).

The rest of the paper is organized as follows: In section 2, the potential method is described briefly. In section 3, the viscous method with primary emphasis on the numerical method is presented. In section 4, results and discussions are presented and in section 5, conclusions are drawn.

POTENTIAL METHOD

Governing equations and boundary conditions

A right-handed Cartesian coordinate system illustrated in Fig. 1 is used throughout the analysis. The origin is chosen at the intersection of the midship and the still water plane. The x-axis is positive in the downstream direction, the y-axis is positive to the starboard side of a ship and the z-axis is positive up-wards. The incoming free stream is parallel to the x-axis and moves to the downstream direction. In the following equations, all the quantities are nondimensionalized by ship speed U and ship length L and the density of a fluid. As mentioned in section 1, the wave breaking is not regarded in the present approach. Thus the free surface shape will be described as a single-valued function of the horizontal coordinates, $z = h(x, y)$.

In potential flow, it is assumed that the fluid is inviscid and incompressible and the motion is irrotational.

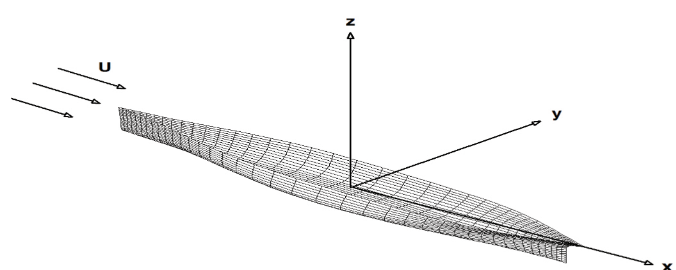

Fig. 1 Coordinate system.

Then the flow can be described by a velocity potential ϕ, which satisfies Laplace equation,

$$\nabla^2\varphi = 0 . \tag{1}$$

In addition we have the Bernoulli equation the constant C being equal throughout the domain.

$$p + \frac{z}{Fn^2} + \frac{1}{2}\nabla\phi \cdot \nabla\phi = C \tag{2}$$