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BEM Computations of 3-D Fully Nonlinear Free-Surface Flows Caused by Advancing Surface Disturbances

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We report on recent developments and validations of a numerical model for free-surface waves generated by an advancing surface disturbance. The model is based on potential flow theory with fully nonlinear free-surface boundary conditions. Equations are solved numerically in the time domain, using a 3-dimensional higher-order Boundary Element Method (HOBEM) combined with a 2nd-order explicit time updating. The generic model, developed in earlier work by Grilli et al. (2000, 2001), is extended in the paper to apply to the present forward-moving disturbance problem. We first assess both the accuracy and convergence rate of the HOBEM for a typical mixed Dirichlet-Neumann problem corresponding to the boundary value problem, which is solved at every time step in the computations. As expected, the convergence rate is found to be 3rd order, and mass and energy are conserved within less than 1% for highly nonlinear waves when at least 8 third-order boundary elements are used per wavelength. To achieve sufficient numerical efficiency for large and finely discretized problems, we use the Fast Multipole Algorithm (*N* log *N* method) recently tested in the model by Fochesato and Dias (2006). As a validation application, we compute 3-D nonlinear free-surface waves caused by a moving pressure patch, such as created by a Surface Effect Ship. Results show that the present methodology works quite well for numerical examples and gives reasonable wave resistance as compared with theory, and other computational results.

INTRODUCTION

According to linear wave theory, a disturbance advancing at steady speed on or below the free surface creates a so-called Kelvin wave pattern, which is completely described in the classical literature. However, surface waves created by a disturbance moving at high speed, such as a Surface Effect Ship (SES), and the resulting wave resistance, may significantly differ from this theory due to nonlinearity. In such cases, it is necessary to tackle the problem numerically and use nonlinear free-surface conditions. In this paper, we briefly review the state-of-the-art in computational methods for ship wave resistance and make recommendations for new directions of development, in light of our recent experience with 3-dimensional Boundary Element Method (BEM) computations of nonlinear free-surface flows (e.g. Grilli et al., 2000, 2001, 2008).

Wave resistance computations for a ship moving at constant forward speed have usually been formulated as a steady flow problem, in a reference frame moving with the ship. Such computations also yield sinkage and trim, which are 2 significant parameters for determining ship hull power requirements and operating condition (Sclavounos et al., 1997).

Initial work on waves generated by a moving vessel can be traced back to Wehausen, and many other precursors of naval hydrodynamics. Most of this classical work covers fundamental aspects and theoretical predictions of wave resistance for simple bodies, such as ship hulls with simplified analytic lines (Wehausen, 1973). A recent review of analytical representations of ship waves can be found in Noblesse (2000). When it comes to numerical computations of wave resistance, the BEM (initially referred to as "panel method" in its lowest approximation) has been widely used since the pioneering works of Hess and Smith (1964) and Dawson (1977). Thus, by the late 1970s, zero and non-zero forward speed problems were beginning to be solved with a BEM, in a so-called Neumann-Kelvin (NK) formulation in which the body boundary condition is satisfied on the mean position of the exact body surface, with linearized free-surface boundary conditions. A further refinement was to use the exact hull boundary condition, but still with linearized free-surface boundary conditions. This approach did not gain popularity, however, and Dawson (1977) devised the so-called double-body or Dawson's approach by linearizing about the double-body flow. An improvement along this line is the weak-scatter hypothesis of Pawloski (1991), where the wave disturbance caused by the ship motion is linearized around the ambient waves, while using the exact ship hull boundary condition; Huang and Sclavounos (1998) utilized this approximation for developing their SWAN 4 model.

By contrast, although more computationally demanding, the Fully Nonlinear Potential Flow (FNPF) approach does not require any approximation of the body or the free-surface boundary conditions. Jensen et al. (1989), Raven (1998), and Liu et al. (2001) reported initial results of using this approach for the steady forward motion. For the unsteady ship wave problem, a time-marching scheme must be used which, as indicated by Beck and Reed (2001), gives rise to additional difficulties, particularly when using an Eulerian-Lagrangian representation. Among these, a very important problem is the local treatment of breaking waves generated around the ship bow and stern, particularly for high-speed ships. Specifically, to be able to pursue numerical simulations with an FNPF-BEM beyond wave breaking, local absorption of wave energy in those regions of the free surface with nearly breaking

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