Nonlinear Diffraction of Waves Over a Submerged Body in a Real Fluid

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ABSTRACT

Nonlinear interaction between surface waves and a submerged slender body is investigated. In the simulation, the incident waves are generated by a paddle type wavemaker. The fully-nonlinear, viscous, wave-body interaction problem is solved using a boundary-fitted coordinates based finite-difference method. Results are obtained for a range of parameters, with particular emphasis on that of small body-submergence and large-amplitude incident waves. In such highly-nonlinear cases, generation of breaking waves and strong free-surface vorticity layers are observed. Time-averaged hydrodynamic force reveal a negative drift force when the body is close to the free surface. Effect of wave motion on the transport of vortical structures is found to be significant in the presence of long incident waves.

KEY WORDS: Wave-body interaction, vortical flow, ocean wave mechanics, Navier-Stokes equations, numerical method.

INTRODUCTION

Prediction and control of motion response to ocean waves is crucial to efficient operation of autonomous underwater vehicles (AUV) in shallow-water environments. Existing controller algorithms were however developed based on somewhat crude hydrodynamics models. These models approximate the hydrodynamic forces using hydrodynamic coefficients that do not properly take into account the free-surface and sea-bottom effects on the dynamics of the vehicle. With the current interest in AUV applications focussed on littoral shallow-water regions, there is a good reason for fully understanding AUV-wave interactions. Even when in deep water, an AUV has to continually approach the surface to seek satellite GPS fixes for the purpose of navigation. Such AUV applications, besides prediction of ship motion in high seas and identification of submerged objects based on free-surface signature and far-field flow structures, are the motivating factors for the present research.

In traditional naval hydrodynamics, the linearized problem of wave-body interactions is decomposed into wave incidence, diffraction, and radiation problems for analysis in the frequency domain (see, e.g., Newman, 1977). The diffraction and radiation problems have similar mathematical structure, in that both have to satisfy the Sommerfeld radiation condition at infinity. In the case of the diffraction problem, the no-flux condition on the body is determined by the incident wave while in the radiation problem by the body motion. There also exists equations such as Haskind relations using which one can determine wave-excited diffraction forces from the hydrodynamic coefficients of the radiation problems. Such analyses have provided valuable results for ship motions in small-amplitude wave fields. Study of ocean vehicles undergoing large-amplitude motions, excited by large-amplitude waves or by resonance, requires however consideration of fully nonlinear free-surface flow problem.

The introduction of a mixed Eulerian-Lagrangian formulation by Longuet-Higgins and Cokelet (1976) has made numerical analysis of fully nonlinear waves and wave-body interactions in an ideal fluid possible, as in Vinje and Brevig (1981) and Groensenbaugh and Yeung (1989). This method of analysis is however of little value for cases in which viscosity effects, such as flow separation, play a key role in the dynamics of wave-body interactions.

In practical ocean engineering, Morison formula is often used to determine inertia and drag force components (see, e.g., Newman, 1977). Determination of the corresponding coefficients is not a trivial matter and the issue of its validity for nonlinear wave-body interaction problems is not yet convincingly settled. The Morison-equation method is after all an empirical approach developed based on the knowledge of hydrodynamic forces acting on a body in infinite fluid. The effect of free surface on such decomposition, in the context of linear wave theory, is discussed in Lighthill (1986).

With powerful computers becoming quite easily accessible for research, hydrodynamicists in recent years have begun developing various numerical methods to study wave-body interactions in a real fluid (see, for e.g., Miyata, 1986a; Ananthakrishnan, 1991 and 1997; Ananthakrishnan and Yeung, 1994; Armenio, 1997; and Gentaz et al., 1996). The success of these efforts suggests that accurate nonlinear solutions to wave-body interaction problems involving complex hull shapes are obtainable, and that these