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Numerical Simulations of the Flow Past Surface-Piercing Objects

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The present study aims to provide further understanding of the dynamics of the breaking waves generated by surface-piercing objects moving with constant forward velocity. The numerical description of such flows is very challenging because of the large deformation and fragmentation of the free surface. Numerical simulations have been conducted by using the δ-SPH model, and the results are compared with results by other CFD solvers and against experimental data.

INTRODUCTION

The main target of the present work is the numerical simulation of the flow around simplified ship bows and around submarine masts. Both of these problems are characterized by the development of complex free-surface deformations with fragmentation and multiple reconnections of the free surface, thus making the numerical modeling of these flows quite challenging.

Bow wave dynamics have long been a subject of theoretical and analytical research in the naval hydrodynamics field (see Ogilvie, 1972). Over the years, impressive progress has been made in the numerical simulation of these kinds of flows (see, e.g., Landrini et al., 2012; Di Mascio et al., 2007). Bow wave dynamics have historically been studied by using simplified geometry as a wedge. Several experimental campaigns on wedges have been done by Miyata and Inui (1984) and Waniewski et al. (2002), while a numerical study has been done in Broglia et al. (2004), and a theoretical study has been done recently in Noblesse et al. (2014). Generally, for these kinds of flows, viscosity and surface tension effects can play a significant role. Therefore, Reynolds and Bond (or Weber) numbers should be taken into account, along with the Froude number, when scaling experimental results from a model test. The experimental results obtained by Waniewski et al. (2002) clearly show that measurements of different model scales in Froude analogy present non-negligible discrepancies. In particular, the analysis confirms a substantial influence of the Froude number on the patterned morphology and highlights the importance of surface tension for small-scale bow ships (e.g., small-scale models tested) in inhibiting the plunging jet formation and evolution. Miyata and Inui (1984) noted that the wave system generated by a traveling wedge is quite similar to the Free Surface Shock Waves characteristic of the shallow water regime. In particular, they showed that the wave system in an open channel flow with a current in a supercritical regime is quite similar to the one generated by the bow of a ship. Following this analogy, Waniewski et al. (2002) showed that the ratio between the model draft and the water depth has no significant effect on the bow wave profile. The bow wave profiles on a wedge model towed in a tank (where the water depth is far larger than the wedge draft) are similar to those obtained in a stationary open channel where the wedge is fixed to the bottom and, therefore, the water depth coincides with the wedge draft.

Another similar naval problem involving surface-piercing objects, but less studied in literature, is the flow around submarine snorkel masts. After an operative submerged condition, a submarine needs to take air from above the water surface through a snorkel mast. The upper part of the intake mast (referred to hereafter as the deplumer; see the right picture of Fig. 1) has to be designed as to avoid any water inflow when operating in snorkel condition. For accurate prediction of the flow around the deplumer, the wave pattern generated by the submarine itself should be taken into account. Indeed, in the region close to the snorkel, the local wave pattern may modify the flow during the interaction with the snorkel mast. As a first approach, a simplified problem is defined by considering the snorkel mast cruising in forward velocity and neglecting the effect of the submarine, as well as the effect of other infrastructures (e.g., periscope, antennas) positioned upstream. This approximation should help in understanding the capability of the deplumer profile to avoid entries of water in the air-intake system. Furthermore, in such a simplified condition, it is possible to perform an experiment in scale 1:1, reproducing the flow at the correct Bond number and avoiding scale effects related to surface tension. Indeed, similar to bow waves, if this flow is reproduced using the Froude analogy on a model scale, the surface tension may inhibit the jet fragmentation, leading to the generation of a uniform sheet of water. On the other hand, in real scale the jet around the mast fragments, generating a cloud of droplets. Furthermore, on a model scale the jet separation from the edges of the deplumer profile may be delayed or even suppressed.

In order to solve the two problems described above, an enhanced variant of the Smoothed Particle Hydrodynamics scheme, the δ-SPH model, has been adopted, and the results were compared to experimental data. At present, some of the most used numerical models for free-surface flows are Finite Volume schemes with level-set or volume-of-fluid algorithms for the free-surface tracking. These solvers are able to deal with 3D breaking wave phenomena (e.g., see Di Mascio et al., 2007). Recently, the SPH method has been used to study the dynamics of breaking waves, proving to be

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