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RANS Simulations of CALM Buoy in Regular and Irregular Seas Using SWENSE Method

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This article recalls the recent developments of the SWENSE (Spectral Wave Explicit Navier-Stokes Equations) method and presents a first validation case for a multidirectional irregular wave field. The SWENSE approach is aimed at simulating fully nonlinear wave-body interactions including viscous effects. It combines the benefits of a potential flow theory used to compute the incident waves and of a Reynolds Averaged Navier-Stokes Equations (RANSE) solver used to obtain the diffracted field in the full domain. As an illustrative application, this article focuses on the case of a captive CALM (Catenary Anchor Leg Mooring) buoy. A full set of wave fields can be generated and the study deals successively with regular waves, head irregular waves and multidirectional head waves. The sharp geometry of the model makes this test case difficult for traditional potential codes and comparatively interesting for the SWENSE method. Results compare favorably with experimental data for all the wave cases.

INTRODUCTION

In the design process for ships and marine structures, numerical simulation has become predominant. Until now, the specific problem of a ship in waves has been mostly addressed using a separation in simpler problems. Resistance and propulsion analysis are mostly performed through viscous flow solvers based on the solution of RANS Equations because these tools are able to catch the viscous effects and the flow separation phenomena at stake. On the other hand, manoeuvering and seakeeping computations are still frequently solved by potential flow theory, which is less time consuming and enables an accurate and efficient description of wave propagation.

The first drawback of such a separation is that these different aspects are strongly coupled. Moreover, neglecting viscous effects in seakeeping problems can lead to poor predictions for cases where strong separation occurs such as rolling for example. Incidentally, the illustrative application we have chosen for this article (a buoy with a skirt) falls in this category. On the whole, it is clear that the natural evolution for computation fluid dynamics (CFD) is to try to address seakeeping and resistance problems within a unified approach by taking into account incident waves in performance predictions.

The classical method used to simulate the viscous flow around a ship advancing in head waves is to impose an incident wave field at the inlet boundary. It is modelled as velocity and pressure perturbations which are added to the uniform stream. These perturbations are usually derived from the linear potential flow solution for free-surface travelling waves. However, such simulations require very large computing resources because grids must be very refined between the location of the structure (at the center of the domain) and the outer boundaries to ensure the propagation with sufficiently low damping.

Due to the massive increase in processing speed and memory capacity, RANSE seakeeping simulations of a ship advancing in regular head waves using this straightforward approach have been possible for a few years. For example, Weymouth et al. (2005) or Visonneau et al. (2008) show very good results compared to state-of-the-art potential simulations. The recent CFD Workshop at Gothenburg (Larsson et al., 2010) has come to a conclusion on the relative maturity for RANSE seakeeping simulations based on different cases of ships advancing in head waves.

However, the straightforward approach encounters 2 major drawbacks. First, the generation of the waves from the boundaries makes it difficult to simulate complex head-wave sea states—such as irregular wave trains or focused waves—and almost impossible to simulate multidirectional irregular waves. Second, successive wave reflections on the body or on the paddle affect the incoming wave train and reduce the useable duration of the numerical simulation; it is indeed very complicated to damp the diffracted field without modifying the incident waves.

To overcome these difficulties, an original formulation is used here by modifying the initial problem in order to solve the diffracted flow only. This approach has previously been used in the frame of potential theory, by Di Mascio et al. (1994) or Ferrant (1996) in 3D cases. It consists in splitting all unknowns of the problem (potential and free-surface elevation) into the sum of an incident term and a diffracted term. The incident terms are described explicitly, using a nonlinear potential flow model. Thus only the part of the grid in the vicinity of the structure needs to be refined. Far from the body, a stretched grid allows an efficient damping of the diffracted flow.

In the SWENSE (Spectral Wave Explicit Navier Stokes Equations) method presented here, incident wave terms are computed with a potential flow model and are then introduced explicitly in a RANSE solver whose equations have been modified by decomposing each physical variable in the sum of an incident variable and a diffracted one. The diffracted field is the only unknown solved by the modified RANSE code. By using this approach, it is possible to simulate various nonlinear incident waves in an efficient and accurate manner: regular wave trains, focused waves, irregular 2D or 3D sea states. Moreover, the useful part of the simulations becomes practically unlimited, because the incident waves and the diffracted field are separated during computation

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