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# Interaction Effects of Local Steady Flow on Wave Diffraction-Radiation at Low Forward Speed

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## ABSTRACT

**The interaction effects of steady flows on wave diffraction-radiation at low forward speed are studied by an analysis based on a decomposition of the time-harmonic potential into linear and interaction components. The linear time-harmonic potential satisfies the classical linearized free-surface condition, while the interaction potential takes into account interaction effects between the local steady flow and the linear time-harmonic potential. Both the linear and interaction potentials are evaluated by using the source method which involves the Green function of wave diffraction-radiation at low forward speed given in Noblesse and Chen (1995). Within the approximation of order $O(\tau)$, the present method yields a consistent solution of the time-harmonic flow around a ship advancing at low forward speed. It is shown that the interaction effects of steady flows at the free surface give substantial contribution to first-order and second-order loadings including wave drift dampings.**

## INTRODUCTION

A body advancing at constant speed in regular waves generates a steady Kelvin pattern plus several systems of linear time-harmonic waves. The general interaction between the steady flow and the time-harmonic flows may be solved by using a zonal approach, which needs considerable effort in solving numerical issues associated with higher-order derivatives of the velocity potential and in required CPU time. One approximate way consists of representing the local steady potential by a double-body flow, which is justified in the low forward speed regime. Solutions of this problem have important applications in offshore technology for estimating the slow-drift excitation on moored ships and the air-gap in the vicinity of oil platforms.

The interaction effects of steady flow on wave diffraction-radiation at low forward speed have been analyzed in a number of studies. Zhao and Faltinsen (1989) used a hybrid method based on matching a local solution in the inner domain to a far-field solution in the outer domain. They found that the wave drift forces are significantly affected even by a low forward speed. Another approach consisting of using the free-surface wave Green function has been developed by Huijsmas and Hermans (1985), Wu and Eatock Taylor (1990) and Nossen et al. (1991). These studies use a perturbation expansion of the Green function and/or the velocity potential with respect to the Strouhal number $\tau = U\omega/g$, where $U$, $\omega$ and $g$ respectively stand for the forward speed, the encounter wave frequency, and the acceleration of gravity. Interesting results, notably for wave drift dampings, have been obtained. Although this perturbation analysis yields useful $O(\tau)$ corrections for forward-speed effects, it suffers from an aesthetic blemish associated with the property that solutions (velocity potential and Green function) contain secular terms unbounded in the far field. Furthermore, this physically unacceptable far-field behaviour can seriously limit practical applications to bodies of large size.

Recently, Noblesse and Chen (1995) performed an analysis of the free-surface potential for general dispersive waves which yields a formal decomposition of the Fourier representation of free-surface effects into a wave component given by a single integral along the dispersion curves, and a local near-field flow component. The application of this analysis to the problem of wave diffraction-radiation at small $\tau$ yields a simple expression for the Green function which can be defined in terms of the Green function for wave diffraction-radiation without forward speed and is uniformly valid in space. The expression for the Green function obtained via a perturbation analysis corresponds to a near-field approximation of the Noblesse-Chen expression. The nonsecular expression of the Green function may also be obtained by using a multi-scale analysis given in Malenica (1997). Application of the uniformly valid Green function to solve the wave-current-body interaction problem is presented here.

Due to the flow symmetry, the wave diffraction-radiation at low forward speed is equivalent to the interaction of waves with a current in the opposite direction. The formulation of this wave-current-body interaction problem is given in Chen and Malenica (1996) and summarized here. The decomposition of the time-harmonic potential into linear and interaction components is then presented, where terms of order $O(\tau^2)$ and higher are neglected. A summary of the Green function for small $\tau$ follows and it is completed in the appendix for its gradients.

Applying the Green theorem to the time-harmonic potentials and the Green function, integral equations are established. The source method is adopted to numerically evaluate the unknown velocity potentials. Expressions for first- and second-order wave loadings, including the radiation coefficients, are given. One difficulty of this source method is the accurate evaluation of the double derivatives of the linear steady potential to obtain the $m_j$ terms on the body surface and the double derivative with respect to $z$ on the free surface. A method inspired from Wu (1991) is developed to evaluate all the terms of the double gradient of the steady potential, without computing the double gradient of the Green function.

Also presented are numerical implementation in our in-house program, and results for an ellipsoid, a half-immersed sphere and

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