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# Comparative Study on Ship Hydrodynamics Based on Neumann-Kelvin and Double-Body Linearizations in Time-Domain Analysis

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**In this study, comparisons between Neumann-Kelvin and double-body linearizations, which are widely applied to a ship motion problem, are carried out on wave excitation forces, hydrodynamic coefficients, motion responses and added resistances. As a method for a solution, a higher-order Rankine panel method is applied in time domain. Computational results obtained by the 2 linearization schemes are compared with experimental data and other computational results on Wigley hulls, the Series 60 hull and S175 containership. Differences between the computational results obtained by the 2 linearization schemes are observed, and the pros and cons are discussed.**

## INTRODUCTION

An accurate prediction of ship hydrodynamics such as ship motions and wave-load is one of the essential elements in ship design. During the past 2 decades, the ship motion problem has been widely studied by means of computational approaches, because numerical schemes have been developed and computing power has considerably matured during the last 20 years. Computational analysis on the ship motion problem has mainly relied on linear analysis, which assumes that a disturbance due to the existence of a body in waves is relatively small. Conventionally, 2 classes of linearization theories have been applied to linearize the ship motion problem: the Neumann-Kelvin and the double-body linearizations. Histories of both linearization schemes are well described in Raven (1996). In spite of popular applications of these 2 linearization schemes to the ship motion problem, only a few comparative studies on the Neumann-Kelvin and double-body linearizations have been introduced. Nakos (1990) compared the steady wave patterns computed by these linearizations. Raven (1996) also compared the steady wave profiles of the 2 linearizations with the measured wave profiles. However, these studies were limited to the wave resistance problem and mostly not for the seakeeping problem. A comparative study on the ship motion problem based on these linearizations is thus carried out in the present work.

As the solution method, a Rankine panel method based on the $B$-spline basis function is applied in time domain. The ship hydrodynamics—such as wave excitation forces, hydrodynamic coefficients, motion responses and added resistances—are computed based on the Neumann-Kelvin and double-body linearizations, including Wigley hulls, the Series 60 ($C_B = 0.7$) hull and S175 containership. By comparing the computational results of the 2 linearization schemes with experimental data and each other, differences between the linearizations are observed, and the pros and cons are discussed in this study.

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KEY WORDS: Seakeeping analysis, Neumann-Kelvin linearization, double-body linearization, time-domain analysis, Rankine panel method.

## MATHEMATICAL BACKGROUND

### Boundary Value Problem and Equation of Motion

Consider a ship advancing with arbitrary forward speed ($U$) in the presence of incident waves. The ship motion is defined in a mean-body fixed coordinate system such as shown in Fig. 1. $A$ and $\omega$ represent incoming wave amplitude and wave frequency, respectively, and $\beta$ is the wave heading angle. If the ship is a rigid body, it has 6 degrees of freedom with the rigid-body translation $\vec{\xi}_T = (\xi_1, \xi_2, \xi_3)$ and the rigid-body rotation $\vec{\xi}_R = (\xi_4, \xi_5, \xi_6)$.

The adoption of potential theory is the typical approach for ship motion analysis. Under the assumption of incompressible and inviscid flow with irrotational motion, the velocity potential ($\phi$) can be introduced, which satisfies the Laplace equation and the following boundary value problem:

$$\nabla^2\phi = 0 \quad \text{in fluid domain} \tag{1}$$

$$\frac{\partial\phi}{\partial n} = \vec{U}\cdot\vec{n} + \frac{\partial\vec{\delta}}{\partial t}\cdot\vec{n} \quad \text{on } S_B \tag{2}$$

$$\left[\frac{d}{dt} + \nabla\phi\cdot\nabla\right][z - \zeta(x, y, t)] = 0 \quad \text{on } z = \zeta(x, y, t) \tag{3}$$

$$\frac{d\phi}{dt} = -g\zeta - \frac{1}{2}\nabla\phi\cdot\nabla\phi \quad \text{on } z = \zeta(x, y, t) \tag{4}$$

where $d/dt = (\partial/\partial t) - \vec{U}\cdot\nabla\cdot\zeta$ and $g$ are the wave elevation and the gravity constant, respectively.

The ship motion can be obtained by solving an equation of motion as follows:

$$[M]\{\ddot{\xi}\} + [C]\{\xi\} = \{F_{F.K.}\} + \{F_{H.D.}\} \tag{5}$$

$[M]$ is the mass matrix of the ship. $\{F_{F.K.}\}$ and $\{F_{H.D.}\}$ are the Froude-Krylov and hydrodynamic forces, respectively. In the traditional linear equation of motion, a constant restoring coefficient ($C$) and a linear Froude-Krylov force are applied under the assumption that the ship motion and wave amplitude are small. Details of numerical implementations about the boundary value problem and the equation of motion are found in Kim et al. (2007).