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Practical Green Function for Thin-Ship Theory

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ABSTRACT

A simple analytical approximation to the local-flow component in the expression for the Green function — associated with the Michell-Kelvin linearized free-surface boundary condition — for the thin-ship theory of potential flow about a ship that advances at constant speed along a straight path in calm water (of effectively infinite depth and lateral extent) is given. The resulting highly simplified Green function provides a practical basis for evaluating the hydrodynamic pressure and wave profile at the hull of a thin ship.

KEY WORDS: thin-ship theory, Green function, ship waves.

INTRODUCTION

Alternative methods for evaluating steady free-surface flow about ships have been developed in the literature. These methods include semi-analytical theories based on various approximations (thin-ship, slender-ship, 2d+t theories), potential-flow panel (boundary integral equation) methods that rely on the use of a Green function (elementary Rankine source, or Havelock source that satisfies the radiation condition and the Michell linearized free-surface boundary condition), and computational fluid dynamics (CFD) methods that solve the Euler or RANS equations. These alternative calculation methods are reported in a huge body of literature, not reviewed here.

Concept design, preliminary design, detail design, and design evaluation are distinct design stages that require distinct computational tools. In particular, practical tools that are simple to use and highly efficient, but need not be highly accurate, are required to quickly evaluate the large number of alternative designs that typically need to be considered during the concept-design and preliminary-design stages. On the other hand, detail design, and especially design evaluation, involve many fewer choices and require more accurate computational tools, for which efficiency and ease of use are less important considerations.

An exceptionally simple and robust method for evaluating steady flow about a ship (advancing along a straight path with constant speed in calm water) is Michell's thin-ship theory; easily the most successful and most widely used theory of steady ship waves. This theory has been applied in numerous studies, not reviewed here, and is still relevant and useful to this day; notably at early design stages (concept-design and preliminary-design) and to evaluate flows about fast ships that (typically) have fine bows.

An important property of Michell's thin-ship theory is that major variables of practical interest (wave profile along ship hull, pressure at ship hull, hydrodynamic lift and pitch moment, sinkage and trim, drag) only require flow calculations at the ship centerplane. Thus, Michell's thin-ship theory defines major features of three-dimensional flow about a ship in terms of calculations that are two-dimensional in nature. In particular, the 2d thin-ship representation of 3d flow about a ship stated in the next section involves a Green function that only depends on two coordinates (instead of three). This Green function of thin-ship theory is considered here. A remarkably simple analytical expression for the local-flow component in the expression for the 'thin-ship-theory Green function' is given.

MICHELL'S THIN-SHIP APPROXIMATION

Steady potential flow about a ship, of length L, that advances in calm water (of effectively infinite depth and lateral extent) with constant speed V_s along a straight path is considered. The X-axis is taken along the path of the ship and points toward the ship bow. The Z-axis is vertical and points upward, and the mean free surface is taken as the plane $Z = 0$. The ship hull is symmetric about the vertical plane $Y = 0$. The flow is observed from a moving system of coordinates attached to the ship and thus appears steady. The flow velocity in this system of coordinates is given by $(U - V_s, V, W)$ where (U, V, W) is the flow due to the ship.

Nondimensional coordinates and flow velocity are defined in terms of a characteristic length L, e.g. the ship length, and the