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Hydrodynamic modeling of semi-planing hulls with air cavities

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ABSTRACT: *High-speed heavy loaded monohull ships can benefit from application of drag-reducing air cavities under stepped hull bottoms. The subject of this paper is the steady hydrodynamic modeling of semi-planing air-cavity hulls. The current method is based on a linearized potential-flow theory for surface flows. The mathematical model description and parametric calculation results for a selected configuration with pressurized and open air cavities are presented.*

KEY WORDS: Semi-planing boat; Stepped hull; Air cavity ship; Method of hydrodynamic singularities.

INTRODUCTION

Fast, shallow-draft, high-payload monohulls are often used for landing military operations. At sufficiently high speeds, these boats move in the semi-planing mode with the hull weight supported by both hydrostatic and hydrodynamic forces. For reducing hull drag by about 10-20% and increasing boat speed, air cavity systems can be applied on the hull bottom (Fig. 1). Stable air cavities can substantially reduce frictional resistance by decreasing the wetted surface area. A review of early developments of air-cavity ships and boats is given by Latorre (1997).

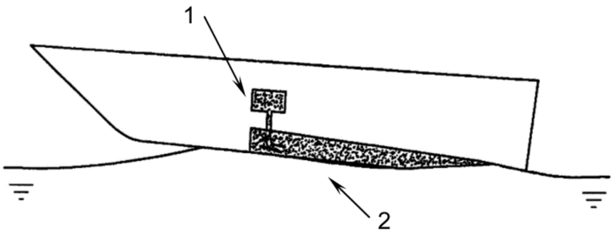

Fig. 1 Air-cavity hull schematic. 1, air blower; 2, air cavity.

Air-cavity landing craft and small fast ferries are already built in series (Matveev, 2005). However, several cases of unsuccessful developments of air-cavity boats are also known (e.g., Tudem, 2002; Dize, 2008). The problem of designing high-performance air-cavity hulls is caused by their more complex hydrodynamics and limited engineering knowledge on this subject in the public domain, including mathematical models for air-cavity flows near hulls. Some developments of numerical methods for planing and displacement hulls are described by Butuzov (1988), Choi et al. (2005), and Thill et al. (2005).

This paper presents a potential-flow method for calculating hydrodynamics of semi-planing hulls with air cavities. The current approach originates from previous models developed by the author for modeling stepless planing hulls at finite Froude

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numbers, air cavities under horizontal walls, and two-dimensional air-cavity stepped hull forms (e.g., Matveev, 2007; Matveev and Ockfen, 2009; Matveev, 2012). Some physical and geometrical simplifications are employed here for the sake of computational efficiency and clarity of the concept presentation. The next section contains an outline of the mathematical model and is followed by calculation examples and discussion.

MATHEMATICAL MODEL

For modeling hydrodynamics of a semi-planing hull with an air cavity, a potential-flow method of hydrodynamic sources is employed. The problem schematic is shown in Fig. 2. The air cavity is formed behind a transverse step on the hull bottom. The air cavity is usually restricted from the sides by narrow skegs; their width is neglected in the present formulation. The water flow is assumed to be inviscid, irrotational and steady. The dynamic boundary condition on the water surface is expressed via Bernoulli equation for the water surface streamlines,

$$p_0 + \frac{1}{2}\rho U_0^2 = p + \frac{1}{2}\rho U^2 + \rho g y_w , \tag{1}$$

where p_0 and U_0 are the pressure and velocity in the far upstream undisturbed water surface at $y=0$, ρ is the water density, and $p(x,z)$ and $U(x,z)$ are the pressure and velocity on the water surface with elevation $y_w(x,z)$. Assuming small trim angles of the hull and sufficiently high hull speeds, flow disturbances caused by the hull presence can be considered to be relatively small. Therefore, the wave slopes and the x-axis velocity perturbation $u = U_x - U_0$ will be small as well. Then, the Bernoulli equation on the free water surface can be linearized and written as follows,

$$\frac{1}{2}\sigma = \frac{u}{U_0} + 2\pi \frac{y_w}{\lambda} , \tag{2}$$

where $\sigma = (p_0 - p)/(\rho U_0^2/2)$ is the cavitation number (zero on the free surface open to atmosphere and non-zero on the surface of a pressurized cavity between the hulls) and $\lambda = 2\pi U_0^2 / g$ is the wavelength on the unconstrained free water surface. The air cavity pressure is treated here as an input parameter. On the wetted hull surface, the same Eq. (2) holds as well, but an unknown and space-dependent pressure coefficient with minus sign is used instead of the cavitation number, i.e., $C_p = (p - p_0)/(\rho U_0^2/2) = -\sigma$.

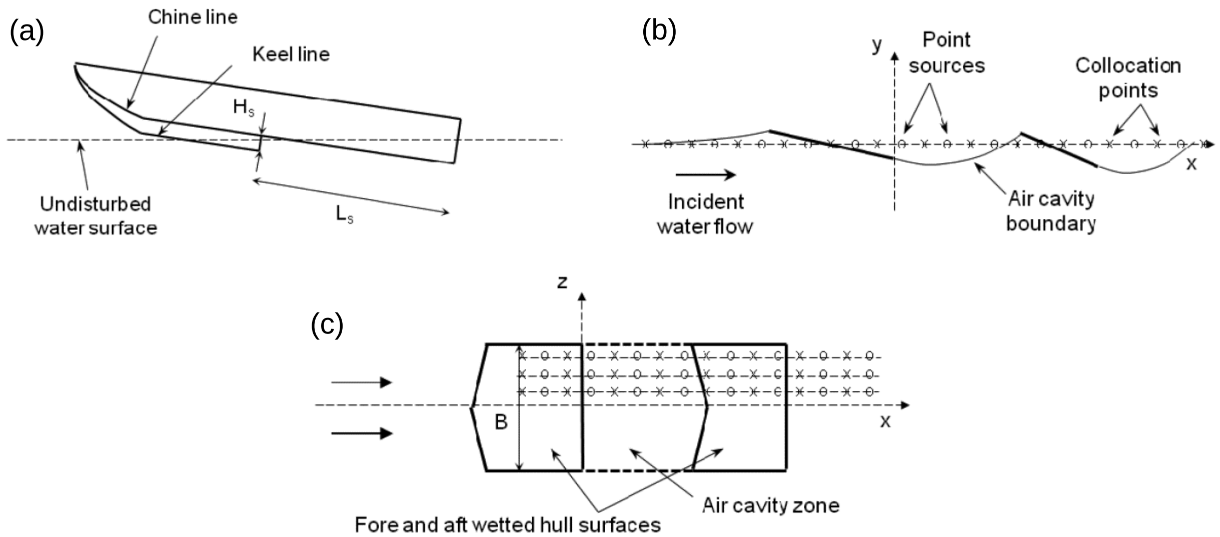

Fig. 2 (a) Side view of a stepped hull. (b) longitudinal cross-section. (c) top view. Circles, point sources; crosses, collocation points. Only a small part of the numerical domain and a small fraction of sources and collocation points are shown.

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