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Modeling of steady motion and vertical-plane dynamics of a tunnel hull

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ABSTRACT: *High-speed marine vehicles can take advantage of aerodynamically supported platforms or air wings to increase maximum speed or transportation efficiency. However, this also results in increased complexity of boat dynamics, especially in the presence of waves and wind gusts. In this study, a mathematical model based on the fully unsteady aerodynamic extreme-ground-effect theory and the hydrodynamic added-mass strip theory is applied for simulating vertical-plane motions of a tunnel hull in a disturbed environment, as well as determining its steady states in calm conditions. Calculated responses of the boat to wind gusts and surface waves are demonstrated. The present model can be used as a supplementary method for preliminary estimations of performance of aerodynamically assisted marine craft.*

KEY WORDS: Tunnel hull; Boat dynamics; Ground-effect aerodynamics; Planing surfaces.

INTRODUCTION

Ultra-fast boats and wing-in-ground craft utilize aerodynamic lift to either partially or completely support the vehicle's weight at sufficiently high speeds. This usually results in increased lift-drag ratio. However, such marine vehicles can also become less stable and respond more dramatically to wind gusts and surface waves (Matveev and Kornev, 2013).

The main subject of this paper is the modeling of the vertical-plane dynamics of a tunnel hull (Fig. 1), which is one of the most common configurations of fast boats with aerodynamic unloading. Side planning hulls on this boat remain in contact with water most of the time, whereas the above-water platform generates aerodynamic support. Linear stability of a tunnel hull was analyzed by Kornev et al. (2010). Some aspects of aero-hydrodynamics, stability and dynamics of other aerodynamically assisted marine craft were considered by Nangia (1987), Collu et al. (2010), Gu et al. (2011), and Matveev (2012).

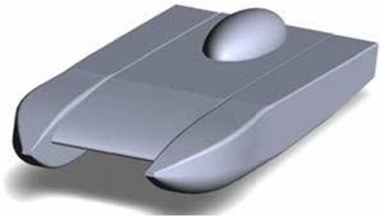

Fig. 1 Three-dimensional render of a simplified tunnel hull.

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To calculate aerodynamic lift on a platform moving above but close to the water surface, the extreme-ground-effect theory can be applied (Rozhdestvensky, 2000). Previously, Chaney and Matveev (2012) utilized a steady quasi-one-dimensional formulation of that theory. In this paper, a fully unsteady nonlinear model with transverse variation of airflow and pressure is implemented. The unsteady hydrodynamic forces on planning hulls are determined with the commonly used added-mass strip theory (e.g., Martin, 1978). The next section outlines the mathematical model, and numerical results for a selected configuration are presented in the following section.

Mathematical model

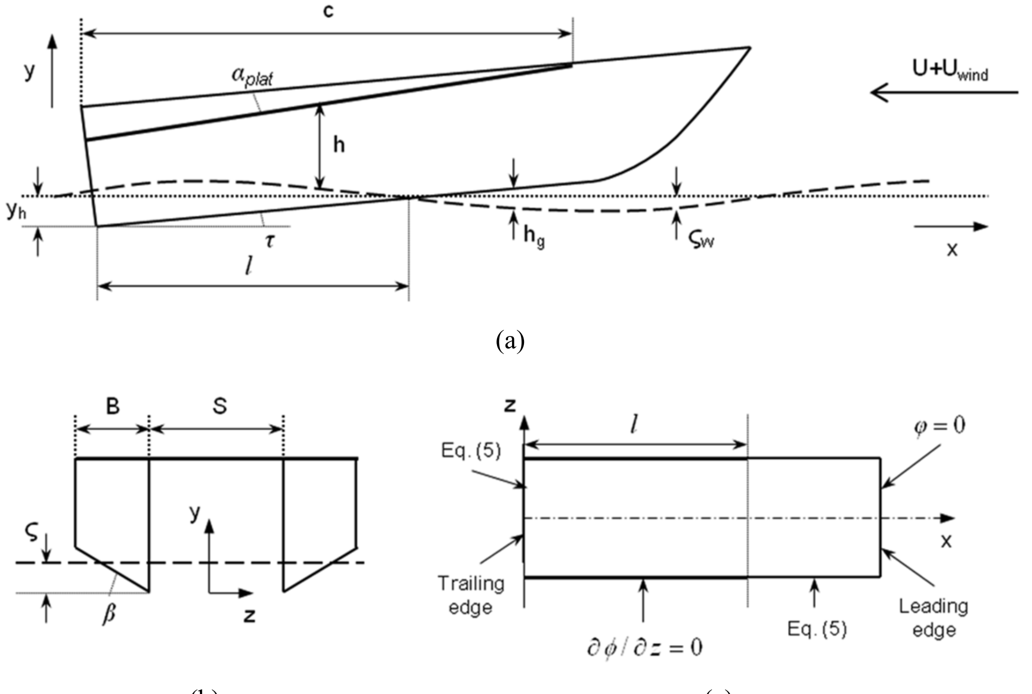
A schematic of a tunnel hull with simplified geometry is given in Fig. 2. Since only vertical-plane motions of this craft at relatively small pitch angles τ are considered here, the vehicle dynamics is governed by the following equations,

$$m\frac{dU}{dt} = T_x - F_D \tag{1}$$

$$m\frac{d^2 y_{cg}}{dt^2} = F_L - mg \tag{2}$$

$$I\frac{d^2\tau}{dt^2} = M \tag{3}$$

where m and I are the boat mass and moment of inertia, respectively, U is the boat horizontal speed, T_x is the horizontal thrust component, F_D is the total drag force, y_{cg} is the vertical position of the center of gravity, F_L is the total lift force, g is the gravity constant, M is the sum of all moments with respect to the center of gravity (CG), and t is the time.



(a)

(b) (c)

Fig. 2 Tunnel hull schematic views. (a) side view. dashed curve represents water surface. (b) front view. (c) top view of the platform with boundary conditions for the aerodynamic sub-model.