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On hydrodynamic analysis of stepped planing crafts

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Abstract

Using transverse steps is one of the adopted strategies to improve the hydrodynamic characteristics of planing crafts. In the present paper, hydrodynamic characteristics of stepped planing crafts are numerically investigated. For this purpose, we analyzed the effects of five different types of transverse steps on lift to drag ratio, resistance, trim angle and sinkage of high speed planing crafts. Contours of pressure distribution on the bottom of crafts, water volume fraction and free-surface are also presented at different hull velocities. Computed numerical results are properly validated against our conducted towing tank experimental tests.

Keywords: CFD; Stepped hull; Lift to drag ratio; Dynamic trim; Sinkage.

1. Introduction

Using transverse steps at the bottom of high speed crafts is one of the well-known strategies to overcome the drag to lift ratio. Indeed, lower bottom wetted area is detectable in the stepped planing crafts due to flow separation on the step. This happens will be resulted to improve of lift to drag ratio. Moreover, these transverse steps provide more uniform pressure distribution on the bottom of vessels (i.e., more longitudinally stability) [1,2]. Two main affective parameters on the hydrodynamic characteristics of the stepped planing crafts are the type of using step and hull velocity (i.e., Froude number). Up to now, various experimental and numerical studies are done to investigate the hydrodynamic characteristics of stepped planing crafts.

One of the first studies is done by Blount and Clement [3] that experimentally investigated drag and fluid flow patterns of high speed crafts. After that, according to some experimental tests, Savitsky [4] suggested some semi-empirical formulations to estimate the drag and lift forces of planing crafts. Drag and lift of planing crafts are numerically studied by Brizzolara and Serra [5]. They validated their results compared to Savitsky [4] and Shuford [6] experimental data. In 2007, Savitsky et al. [7] studied the impression of whisker spray on the drag of planing crafts. Then, in 2010, aftbody wake profiles of prismatic planing crafts were experimentally investigated by Savitsky and Morabito [2]. In the recent years, resistance and sea keeping of a planing craft embedded via wave-piercing and spray rails is experimentally studied by Seo et al. [8]. Jiang et al. [9] studied hydrodynamic behavior of trimaran planing hull at different Froude numbers. In both experimental and numerical studies, fluid flow pattern around the one-step planing craft is investigated by De Marco et al. [10]. Influences of artificial air cavity on resistance components of planing hull are also investigated by Cucinotta et al. [11]. In 2019, Sajedi et al. [12] studied the impression of wedge on porpoising of planing crafts by using both numerical and experimental studies. Masumi and Nikseresht [13] numerically simulated 2D motion of high speed planing crafts in head sea waves. Doustdar and Kazemi [14] investigated the effects of fixed mesh and dynamic mesh on CFD simulation of stepped planing crafts. They found that the porpoising phenomenon is just visible by dynamic meshing method for Cougar stepped planing craft.

Study on the effects of geometrical parameters of the step on hydrodynamic characteristics of stepped planing crafts is another interested issue. Therefore, some literature studies on

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Table 1
Some literature studies on the geometrical parameters of the step in stepped planing crafts.

Author	Technique	Evaluated geometrical parameters
Clement and Pope [15]	Experimental	• Deadrise
Clement and Koelbel [16]	Experimental	• Shape of the step profile
Svahn [17]	Analytical and numerical	• Deadrise • Height • Distance from transom
Makasyeyev [18]	Analytical	• Shape of the step profile
Savitsky and Morabito [2]	Experimental	• Shape of the step profile • Height • Distance from transom
Taunton et al. [19]	Experimental	• Deadrise • Shape of the step profile
Taunton et al. [20]	Experimental	• Deadrise • Shape of the step profile
Lee et al. [21]	Experimental	• Deadrise • Shape of the step profile • Height • Distance from transom
Timmins [22]	Experimental	• Deadrise • Shape of the step profile • Height • Distance from transom
Lotfi et al. [23]	Numerical	• Shape of the step profile
De Marco et al. [10]	Experimental and numerical	• Deadrise • Shape of the step profile • Height

Table 2
Main features of Fridsma planing hull.

Parameter	Value
Overall length (m)	2.5
Beam (m)	0.5
Length to beam ratio	5
Draft at aft perpendicular (m)	0.113
Displacement (N)	478.72
LCG (m)	0.9
VCG (m)	0.091
Trim (deg)	1.26
Deadrise angle (deg)	20

the effects of geometrical parameters of the step in stepped planing crafts are tabulated in Table 1.

Based on the literature review, the lack of study related to investigate of different types of the steps on hydrodynamic characteristics of stepped planing hull is evident. Indeed, impression of different types of transverse steps on the hydrodynamic behavior of high speed planing crafts is not well-known so far. So, in the present paper, we investigated the hydrodynamic characteristics of Fridsma stepped planing hulls with five different types of steps (i.e., with different geometrical parameters). For this purpose, lift to drag ratio, hydrodynamic resistance, dynamic trim angle and sinkage of considered stepped planing craft are numerically investigated. Moreover, contours of pressure distribution on the bottom of intended crafts, contours of volume of fluid and free-surfaces at different hull velocities are presented and discussed. It is also notable that, our numerical data are validated compared to experimental results conducted by authors at the national Iranian marine laboratory (NIMALA), Tehran, Iran.

2. Physics of the problem and methods

2.1. Physical model and numerical procedure

In this study, Fridsma planing craft is considered. In Table 2, main characteristics of Fridsma planing hull is presented.

In order to simulate of fluid flow around the planing hull, Cartesian form of Reynolds averaged version of Navier–Stokes equations (RANSE) are considered as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial u_i}{\partial x_i} = 0, \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\underbrace{\mu_{eff}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)}_{\tau_{ij}}\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u'_i u'_j}\right) + g_i. \tag{2}$$

where Cartesian coordinates are shown by x_i and x_j. In addition, velocity components are presented in form of u_i and u_j and p, ρ, g_i , μ and τ_{ij} are pressure, density, gravity acceleration, viscosity and Reynolds stress tensor, respectively. Effective viscosity is also shown by μ_{eff} (i.e.,$\mu_{eff} = \mu + \mu_t$). In this study, standard k–ε turbulence model is selected. In this turbulence model, k and ε are representative of kinetic