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Mathematical Model of Dynamics of Air Cushion Vehicle with Ballonet Type Skirt on Water

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Abstract

The mathematical model of the dynamics of an Air Cushion Vehicle with a ballonet type skirt is presented. This model incorporates a number of interrelated submodels representing different constituents of ship dynamics: rigid body, air cushion, propulsion system, ballonet, underlying surface, aerodynamics, yaw rudder. The proposed model is capable of predicting all major characteristics of the ship movement such as trajectory, forces, moments, air cushion pressure, subject to different operating conditions. Both controlled and uncontrolled movement may be simulated. The suggested approach is based on the numerical integration of the equations of motion as well as the equation describing the pressure evolution in the air cushion. The verification of the model was carried out and the results of model towing tests are presented.

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Keywords: Air-cushion vehicle; ballonet type skirt; mathematical model; towing tank; model test.

1. Introduction

The object of the study is the amphibious air-cushion vehicle (ACV) with ballonet type skirt. Side part of the skirt is made of flexible tubes containing pressurized gas. This type of ships is developing in the Russian market of high-speed shipbuilding rather successfully [1]. They occupy an intermediate position between Surface Effect Ships (SES) with rigid submerged hulls and ACV with a flexible classical type skirt. Flexible inflatable side skirt allows such ships moving on ice, snow, sand etc. Semi submerged inflatable ballonets provides increased buoyancy of the vessel compared to the ACV with a classical skirt, as well as stability and sustainability on the course. Ballonets damp forces during the motion on a solid or deformable surface (e.g., snow). As a result, loads acting on the ship's

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hull are getting smaller and more evenly distributed. Thus, ACV with ballonet type skirt combines best features of ACV with classic skirt and SES: amphibious qualities, maneuverability, stability and hence safety in use.

Figure 1 shows the production samples of ACV with ballonet type skirt "Hivus-10" and "Hivus-48", full displacement 2.3t and 18t respectively.

The aim of this article is to present a model of dynamics of ACV with ballonet type skirt. Admittedly, such a model must satisfy conflicting requirements: adequately reflect the dynamic processes in ACV's systems and still be simple enough to obtain results with acceptable time-consuming. The most simple in terms of the implementation is a model that considers the motion of the ship as a rigid body with six degrees of freedom (three displacements and three rotations) under the action of external loads from the air cushion, contact with the supporting surface, propulsion thrusters, as well as loads from external aerodynamic flow around the ship.

The main results concerning the dynamics of ACV with classical type skirt on the water surface were obtained in 1960-1970. In 1972, Reynolds [2] evolved the linear equations of motion for ACV based on the condition that skirts do not physically come into contact with the water surface and Froude-Krylov hypothesis was assumed to be valid. Nonlinear equations of motion are given by Doctors [3,4] and Yun [5]. They took into account the compressibility of the air in the air cushion and non-linear characteristics of the blowers. Carrier [6] solved the problem of the ACV's motion in waves under the assumption of absolute rigidity of flexible protection elements. Later these results were summarized in the form of physical and mathematical basis of ACV dynamics in monographs [7-9].

In order to simulate ACV dynamics accurately it is necessary to take into account hydrostatic and hydrodynamics loads acting on the ballonet in contact with water. These calculations are carried out in the same way as it is recommended in the calculation of forces acting on the SES [10].

Development of computational fluid dynamics (CFD) methods yielded qualitatively new data for the calculation of ACV dynamics based on the numerical solution of the averaged Navier-Stokes equations of turbulent flow of a viscous incompressible fluid with boundaries between media [11,12]. Thus it is possible to obtain aerodynamic longitudinal and lateral characteristics ACV, as well as the aerodynamic efficiency of controls at various positions of ship in space [13]. This data is used extensively for the dynamics simulations.

Proposed mathematical model is verified by a comparison of the results predicted by the suggested technique with the results of the model towing tests in calm water and regular wave carried out in a high-speed towing tank Krylov State Research Center.

Fig. 1. ACV with ballonet type skirt.

2. Model of the Vehicle

The proposed model of ACV's dynamics consists of a number of interrelated submodels: equation of ACV motion in 3D space, equations of change of pressure in the air cushion sections, contact model between skirt and water surface, aerodynamic characteristics model (including the rudder system), propulsion system model, lift system model, water surface model.

Dynamics of ACV is described by a rigid body's equations of motions. Cushion pressure in every air cushion section is assumed to be homogenous and can be calculated from equations (1) [8]: