Ocean Engineering 131 (2017) 322–337

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Dynamic modeling of sail mounted hydroplanes system-part II: Hydroelastic behavior and the impact of structural parameters and free-play on flutter

Chen Dongyang[a], Laith K. Abbas[a,*], Rui Xiaoting[a], Xiao Qing[b], Pier Marzocca[c]

[a] Institute of Launch Dynamics, Nanjing University of Science and Technology, Nanjing 210094, China
[b] China Ship Development and Design Center, Wuhan 430064, China
[c] School of Engineering, Aerospace Engineering and Aviation Discipline, RMIT University, Melbourne, VIC 3000 Australia

ARTICLE INFO

Keywords:
Hydroplanes system
Fluid-structure interface
Two-way coupling
Hydroelasticity
Free-play
Limit cycle oscillations

ABSTRACT

Flutter of sail mounted hydroplanes system is a self-excited dynamic hydroelastic phenomenon due to an undesirable coupling occurring between the elastic structure and hydrodynamic flows. The flutter behavior depends on both structure parameters and free-play nonlinearities in the hydroplanes system. The free-play nonlinearity introduces persistent limit cycle oscillations (LCO) which can cause water noise, and it will have an undesirable effect on the concealment capability of marine vehicles. The impact of structure parameters and free-play of the hydroplanes systems on the hydroelastic stability is not fully understood and is an active area of research. In order to explore the fundamental nature of the hydroplanes system, the present paper, Part II of this work, focus on two aspects: (i) the analysis of the full-scale hydroplanes system hydroelastic response based on Computational Fluid Dynamics/Computational Structure Dynamics (CFD/CSD) two-way coupling method which verified by the AGARD 445.6 wing standard flutter model. Results show that the hydroplanes system hydroelastic response is completely symmetrical, and it proves Part I work, that is the full-scale system can be simplified as one hydroplane with a torsional spring. Additionally, (ii) the 2-DOF structural model and the Theodorsen's theory of hydroplanes system are used to get a better understanding of the structure parameters and free-play effect on linear/nonlinear flutter of the hydroplanes system. To validate the accuracy of the modeling predictions, the linear/nonlinear simulation in-home codes are compared with those theoretical and experimental reported in the existing literature, and good results within engineering error margins are obtained. Results show that structural parameters might effect on the classical flutter speed and LCO only occurred in low flow speed due to free-play.

1. Introduction

In Part I of this work (Chen et al., 2016), a sail mounted hydroplanes system based on Transfer Matrix Method of Multibody systems (MSTMM) was modeled, and the aim was to understand the natural vibration behaviors of the full-scale hydroplanes system. It is shown that an equivalent model consisting of one hydroplane with a torsional spring can capture the dynamics behavior of the full-scale hydroplanes system. The system shows symmetric (modes 1 and 3) and anti-symmetric (modes 2 and 4) modes. The later one are local modes, that is modes 2 and 4 are contributing to the local behavior of the structure and do not participate to the global dynamics which is the problem being assessed in this paper. For the structural dynamic behavior and response analysis, the influence of these local modes can be safely neglected. As a result, the system is symmetric and can be simplified to consider just half of the system. Moreover, the uncoupled pure bending and torsion frequencies as the main parameters of two degrees-of-freedom (2-DOF) structural model are obtained from the MSTMM analysis.

The term hydroelasticity was coined for the first time by Heller and Abramson (Heller and Abramson, 1959). They defined hydroelasticity as the naval counterpart to aeroelasticity and recognized that at fluid structure interaction level significant differences may exist between the hydrodynamic, inertia, and elastic forces experienced by a floating marine structure (Hirdaris and Temarel, 2009). In other words, hydrodynamic loads can induce elastic structural deformations, which in turn can change the flow-field distribution. The physical properties of this kind of interaction are the coupling phenomena of the fluid to the inertia force, damping, and elastic force of the elastic structure system. Dynamics of flutter is an important consideration in the design

* Corresponding author.

http://dx.doi.org/10.1016/j.oceaneng.2017.01.013
Received 26 June 2016; Received in revised form 21 December 2016; Accepted 7 January 2017
Available online 18 January 2017
0029-8018/ © 2017 Elsevier Ltd. All rights reserved.

of hydrofoil structures. In order to explore the fundamental nature and improve structure performance of marine sail mounted hydroplanes system, the hydroplanes should be considered as flexible body.

Fluid-structure interaction (FSI) analysis can be performed by coupled Computational Fluid Dynamics (CFD) and Computational Structural Dynamics (CSD) simulations. FSI problems play prominent roles in many scientific and engineering fields, yet a comprehensive study of such problems remains a challenge due to their strong nonlinearity and multidisciplinary nature (Chakrabarti, 2005; Dowell and Hall, 2001; Morand and Ohayon, 1995; Mian et al., 2014; Yang et al., 2012; Dang et al., 2010; Lakshmynarayanana, 2015). For most engineering FSI problems, analytical solutions to the model equations are impossible to obtain; on the other hand, laboratory experiments are limited in scope, hence to investigate the fundamental physics involved in the complex interaction between fluids and solids, numerical simulations are often considered a suitable approach. The use of full-scale 3-dimensional CFD solutions overcomes some shortcomings of combining a series of strip or 2-dimensional simulations to calculate the fluid forces on the hydroplanes (Holmes et al., 2006). Sail set at high angles of attack and speeds capable of generating high turbulence, separation flow and vortex shedding are among the major sources of hydrodynamic nonlinearities which can affect the hydroelastic behavior of the hydroplanes system.

The first aim of Part II is to investigate the hydroelastic response behavior of full-scale hydroplanes system based on CFD/CSD two-way coupling and taking advantage of grid deformation tools.

The effect of structural parameters on the hydroelastic behavior of hydroplanes system is investigated to ensure their structural safety. There are vast amounts of literature using 2-DOF structural model (the typical section model); Theodorsen and Garrick (Theodorsen, 1949; Theodorsen and Garrick, 1940), for example, used this model to study the aero/hydro-elastic problems of the aero/hydro-foil system. In marine applications, the poorly designed hydrofoil may exhibit the classical flutter or static divergence problem which will lead to catastrophic structural failure (Abramson, 1969; Besch and Liu, 1974; Ducoin and Yin, 2013; Chae et al., 2013). Moreover, free-play nonlinearity may occurred in the actuator/steering engine or the links of the mechanism or support mechanism of hydroplanes system and would introduce persistent limit cycle oscillations (LCO) (Abbas et al., 2008a; Li et al., 2012; Shin et al., 2007), and although it will not lead to catastrophic failure, will significantly contribute to increase the noise signature, reducing the stealth capability of a marine vehicles.

For purposes of theoretical flutter prediction, inertia and geometric properties of a lifting surface/or control surface can be represented by a typical section with inertia and geometric properties of the surface at ¾ of the distance from the root of the wing (Marzocca et al., 2001; Dimitriadis and Cooper, 2001; Encyclopedia of Aerospace Engineering, 2010). This suggestion holds for lifting surfaces with high aspect ratio and small sweep, and the sectional characteristics vary smoothly across the span. The typical section representation is not only suitable for cantilever wing simulation but also for control surface (such as hydroplanes) aero/hydro-elastic analysis. Control surfaces are assumed to be chordwise rigid and obey the thin airfoil assumption. Since the control surface is connected to the control unit via a torsionally less stiff shaft than the control surface, it can be assumed that elastic rotation takes place at the connecting shaft only. The mechanical components of the servo system such as steering engine or links of the mechanism, and free-play nonlinearity on these components will decrease the *equivalent torsional stiffness* (the stiffness which replaced instant of the entire system) of the hydroplanes system, and the bending stiffness is much larger than torsional stiffness due to relatively low aspect ratio and equivalent stiffness.

Strictly speaking, CFD/CSD two-way coupling numerical simulation is a high-fidelity approach but it is still computationally expensive. Moreover, hydroelastic simulations with various structure parameters such as the location of elastic axis, centroid position, mass and stiffness of the hydroplanes and free-play nonlinearity of the full-scale sail mounted hydroplanes system are difficult when considering geometrical features and appropriate weight and shape specifications. Thus, the second aim of this paper is studying the impact of structure parameters and free-play nonlinearity on LCO and flutter of the hydroplanes system based on 2-DOF structure model considering both the Theodorsen's theory and the uncoupled pure bending and torsion frequencies which have been obtained in Part I via MSTMM (Chen et al., 2016).

2. Modeling of hydroplanes system

2.1. Fluid -structure Interactions (FSI) modeling of full-scale hydroplanes system

The rigid geometry assumption holds for many engineering structural problems. However, if the structure is flexible, fluid-structure interactions predictions become more and more important. The deflection of the elastic structure tends to redistribute the hydrodynamic loads acting on the hydroplanes and this interaction continues in a full feedback mode. Toward the first aim of this study, the commercial software ANSYS®-CFX is used as the hydrodynamics solver and ANSYS®-CSD is used as structural solver, along with grid deformation and the two-way FSI coupling carried out in ANSYS Workbench® (ver. 16.0) multi-physics (ANSYS, 2015) to simulate numerically the hydroelastic response of the full-scale hydroplanes system.

2.1.1. Fluid model

Direct Numerical Simulation (DNS) solves Navier-Stokes (N-S) equations directly without any turbulent model. However, DNS required a large amount of memory and supercomputing power especially for large scale system with modeling nonlinearities and complexities, and it is impossible to adopt this method in the solution of practical engineering problems. On the other hand, when N-S equations are expressed in a Reynolds Averaged Navier-Stokes (RANS) form it is possible to simulate viscous fluid dynamics phenomena. RANS equations can be expressed as

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho \bar{u}_i)}{\partial x_i} = 0,$$
$$\frac{\partial(\rho \bar{u}_i)}{\partial t} + \frac{\partial(\rho \bar{u}_i \bar{u}_j)}{\partial x_j} = -\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left[2\mu\left(S_{ij} - \frac{1}{3}S_{kk}\delta_{ij}\right)\right] + \frac{\partial}{\partial x_j}(-\rho \bar{u}'_i \,\bar{u}'_j) \tag{1}$$

where,

$$-\rho\overline{u_i' u_j'} = R_{ij} = -\rho\begin{Bmatrix} \overline{u'u'} & \overline{u'v'} & \overline{u'w'} \\ \overline{v'u'} & \overline{v'v'} & \overline{v'w'} \\ \overline{w'u'} & \overline{w'v'} & \overline{w'w'} \end{Bmatrix} = \mu_t\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right)$$
$$-\frac{2}{3}\delta_{ij}\left(\rho k + \mu_t \frac{\partial \overline{u_m}}{\partial xm}\right),\ S_{ij} = \frac{1}{2}\left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right)$$

and where u, ρ, p, and μ are the fluid velocity, density, pressure, and dynamic viscosity, respectively. S_{ij} is the instantaneous strain rate tensor. Eq. (1) then introduces a set of unknowns called the Reynolds stresses R_{ij} which are functions of the velocity fluctuations. The present simulations make use of the $k-\omega$ Shear Stress Transport (SST) turbulence model developed by Menter (Menter, 1993, 1994) to compute R_{ij} to closure Eq. (1). The SST model considers $k-\varepsilon$ and $k-\omega$ models as they are used to calculate the flow structure inside and outside the boundary layer. Blending function F_1 is used to $k-\varepsilon$ and $k-\omega$ models. The constant ϕ of the SST model is calculated from the two constants, ϕ_1 and ϕ_2 as follows

$$\phi = F_1\phi_1 + (1 - F_1)\phi_2 \tag{2}$$

Set 1 (ϕ_1) is the constants of the $k-\omega$ model and set 2 (ϕ_2) is the constants of $k-\varepsilon$ model. All other equations and parameters are given in (Menter, 1993, 1994).

Download English Version:

https://daneshyari.com/en/article/5474547

Download Persian Version:

https://daneshyari.com/article/5474547

Daneshyari.com