Applied Ocean Research 51 (2015) 14–24

Contents lists available at ScienceDirect

Applied Ocean Research

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

Numerical investigation of the hydrodynamic interaction between two underwater bodies in relative motion

S.A.T. Randeni P.[a,*], Z.Q. Leong[a], D. Ranmuthugala[a], A.L. Forrest[a,b], J. Duffy[a]

[a] Australian Maritime College, University of Tasmania, Launceston, Australia
[b] Tahoe Environmental Research Center, University of California – Davis, Incline Village, NV, USA

ARTICLE INFO

Article history:
Received 6 August 2014
Received in revised form 6 February 2015
Accepted 11 February 2015
Available online 10 March 2015

Keywords:
Underwater body interaction
Computational Fluid Dynamics
Autonomous Underwater Vehicles
Hydrodynamic coefficients
Manoeuvring simulations

ABSTRACT

The hydrodynamic interaction between an Autonomous Underwater Vehicle (AUV) manoeuvring in close proximity to a larger underwater vehicle can cause rapid changes in the motion of the AUV. This interaction can lead to mission failure and possible vehicle collision. Being self-piloted and comparatively small, an AUV is more susceptible to these interaction effects than the larger body. In an aim to predict the manoeuvring performance of an AUV under the effects of the interaction, the Australian Maritime College (AMC) has conducted a series of computer simulations and captive model experiments. A numerical model was developed to simulate pure sway motion of an AUV at different lateral and longitudinal positions relative to a larger underwater vehicle using Computational Fluid Dynamics (CFDs). The variables investigated include the surge force, sway force and the yaw moment coefficients acting on the AUV due to interaction effects, which were in turn validated against experimental results. A simplified method is presented to obtain the hydrodynamic coefficients of an AUV when operating close to a larger underwater body by transforming the single body hydrodynamic coefficients of the AUV using the steady-state interaction forces. This method is considerably less time consuming than traditional methods. Furthermore, the inverse of this method (i.e. to obtain the steady state interaction force) is also presented to obtain the steady-state interaction force at multiple lateral separations efficiently. Both the CFD model and the simplified methods have been validated against the experimental data and are capable of providing adequate interaction predictions. Such methods are critical for accurate prediction of vehicle performance under varying conditions present in real life.

Crown Copyright © 2015 Published by Elsevier Ltd. All rights reserved.

1. Introduction

Autonomous Underwater Vehicles (AUVs) are used in civilian, academic, and military applications due to their ability to undertake complicated tasks underwater without real-time user control. A few examples of such applications include underwater surveillance [1] and sampling physical transport processes in lakes [2]. AUVs are increasingly required to operate close to larger underwater vehicles such as submarines and larger Remotely Operated Vehicles [3], as well as to operate in swarms of AUVs of similar size [4]. When operating in close proximity to a larger moving vehicle like a submarine, an AUV can experience motions resulting from the interaction of the wake and pressure fields generated by the larger body [5]. Being relatively small and self-piloted, the AUV is more susceptible to these interaction effects, which can result in mission failure and, in extreme cases collision between the two vehicles. For this reason, it is critical to understand the manoeuvring performance of an AUV under these interaction effects in order to develop adequate control strategies [6].

While there have been considerable studies on hydrodynamic interactions between surface ships [7–9], there is currently very little information on the interaction between submerged vessels in the public domain. Mawby et al. [10] developed a high level architecture model to simulate the interaction between a moving submarine and a rescue submersible manoeuvring to the escape hatch of the submarine. This earlier model utilized pre-processed hydrodynamic interaction data obtained by solving the Laplace's equation using a boundary element method for the inviscid, irrotational flow past the vehicles' surfaces. The limitation of the utilized potential flow approach is that it does not account for fluid viscosity or wake field effects of the vehicles and will potentially oversimplify the interaction effects.

Previous numerical and experimental studies by Leong et al. [6] have investigated the interaction effects on an AUV operating close to a larger vehicle for diameter ratios between the vehicles ranging from 2.237:1 up to 13.425:1 (i.e. displacement ratio from 10.419:1 to 139.878:1 respectively). The influence of different

* Corresponding author at: Locked Bag 1395, Launceston, TAS 7250, Australia. Tel.: +61 47 047 6942.
E-mail address: Supun.Randeni@utas.edu.au (S.A.T.R. P.).

0141-1187/$ – see front matter. Crown Copyright © 2015 Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.apor.2015.02.006

Nomenclature

D	diameter of the body [m]
Fy	sway force [N]
Fy'	non-dimensional sway force coefficient, $\frac{2Fy}{\rho L^2 U^2}$
L	overall length of body [m]
L_S	surface length of body [m]
m	mass of body [kg]
N	Yaw moment [Nm]
N'	non-dimensional yaw moment coefficient, $\frac{2N}{\rho L^3 U^2}$
Re	Reynolds number
R_{lat}	lateral body separation ratio
R_{long}	longitudinal body separation ratio
u	forward velocity [m/s]
v	sway velocity [m/s]
$\dot{v}$	sway acceleration [m/s^2]
$y+$	non-dimensional distance from wall to first node
Y_v	sway force coefficient due to sway velocity [N]
$Y_{\dot{v}}$	sway force coefficient due to sway acceleration [N]
Δ	displacement [m^3]
ω	sway frequency [rad/s]

lateral and longitudinal distances between the two bodies over a range of speeds were investigated through Computational Fluid Dynamic (CFD) simulations and validated with captive model experiments [6]. Leong [11] also carried out dynamic CFD simulations, modelling the pure sway motion of a smaller AUV model in close proximity to a larger AUV at one relative longitudinal position.

The work presented in this paper complements this previous work by considering a larger range of longitudinal positions and sway motion frequencies, with the information presented for a diameter ratio of 2.237:1 (i.e. displacement ratio of 10.419:1). The authors have also extended the capabilities of the CFD numerical model to simulate pure yaw motion of the AUV in close proximity to a larger body; however, will not be presented in this work. The numerical model was developed in ANSYS-CFX, utilizing re-meshing techniques and was validated against experimental work conducted in the Towing Tank of the Australian Maritime College (AMC) at the University of Tasmania. Once validated, this numerical model can be extended to investigate the interaction between vehicles of larger diameter ratios, thus better representing the interaction between typical submarines and AUVs. A simplified method is presented to obtain the hydrodynamic coefficients of an AUV when operating close to a larger underwater body by transforming the single body hydrodynamic coefficients, using the steady state interaction forces. Using this method, the variation of hydrodynamic coefficients due to a second body could be estimated by conducting a less time consuming steady-state simulation, rather than time intensive dynamic pure sway motion simulations. Furthermore, the inverse of this method (i.e. to obtain the steady state interaction force) is also presented and validated. Inverse method is an efficient way of obtaining the steady-state interaction force at multiple lateral separations.

2. Methodology

2.1. Geometric models

The hydrodynamic characteristics of an AUV operating close to a larger underwater body were investigated through CFD and Experimental Fluid Dynamics (EFD) using two axisymmetric bare-hull underwater vehicle geometries. The research utilized a 1:2.801 scaled model of the SUBOFF submarine hullform developed by the

Table 1
Principal particulars of the two models.

	SUBOFF model	NP01 model
Length (L)	1.438 m	2.850 m
Diameter (D)	0.181 m	0.410 m
Displacement (Δ)	0.031 m^3	0.323 m^3

Defence Advanced Research Projects Agency (DARPA) [12] as the smaller AUV, and a larger torpedo-shape body designated as NP01, with the principal dimensions of the models are shown in Fig. 1(a) and Table 1. The diameter ratio of the NP01 model to the SUBOFF model is 2.237:1. The model scales were selected to ensure that they were sufficiently small to fit within AMC's towing tank without causing blockage effects, but large enough to provide magnitudes of interaction forces that are larger than the experimental error levels.

2.2. Test parameters

The test runs consisted of straight-line and pure sway motions of the SUBOFF at different relative longitudinal and lateral positions to the larger NP01, with the investigated variables consisting of the surge force, sway force and the yaw moment experienced by the SUBOFF model. The lateral distance between centrelines of the two bodies was assumed to be the lateral separation distance, while the longitudinal separation distance was measured from the nose tip of the larger NP01 vehicle to that of the smaller SUBOFF vehicle; a 'positive' distance signifying that the SUBOFF model is located in front of the larger vehicle as shown in Fig. 1(a). The longitudinal and lateral distances were non-dimensionalized as follows:

$$\text{Longitudinal separation ratio} \quad (R_{long}) = \frac{\text{Distance SUBOFF nose tip to NP01 nose tip}}{\text{Length of NP01}} \tag{1}$$

$$\text{Lateral separation ratio} \quad (R_{lat}) = \frac{\text{Lateral separation distance}}{\text{Diameter of NP01}} \tag{2}$$

The coordinate system was selected according to [13] as shown in Fig. 1(b).

In order to isolate the interaction forces due to the larger second body, single body testings of the SUBOFF were conducted to provide baseline data. A summary of the single-body and two-body test parameters is outlined in Table 2. The estimated Reynolds number (Re_{L_S}) is based on the length of the SUBOFF model, which is 1.438 m.

2.3. Definition of test motions

2.3.1. Straight-line motion

In the straight-line motion experiments, the bodies were moved in an equal forward velocity with a zero angle of attack. The aim of these tests was to obtain the sway and drag forces on the smaller SUBOFF body due to the forward motion when it is alongside the larger body. The obtained forces are referred to as the forces due to 'steady state straight-line motion'.

2.3.2. Pure sway motion

In the pure sway motion experiments, the SUBOFF model was moved forward at a constant velocity while undergoing sinusoidal oscillations in the y direction around its centre line (see Fig. 2) in order to obtain the surge force, sway force and the yaw moment due to sway velocity and sway acceleration. The angle of attack was maintained at zero. In pure sway motion, the sway displacement (y) is 90° out-of-phase with the sway velocity (v). The sway acceleration ($\dot{v}$) is in-phase with the sway displacement, while being 90°

Download English Version:

https://daneshyari.com/en/article/1719967

Download Persian Version:

https://daneshyari.com/article/1719967

Daneshyari.com