Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(7) (2020) 499-502
DOI: 10.22060/mej.2019.15237.6066

Roll Dynamic Stability of an Autonomous Underwater Vehicle with a Fish-like Hull Shape

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ABSTRACT: An autonomous underwater vehicle designed and manufactured with fish-like hull shape in order to survey subsea pipeline and cable is analyzed hydrodynamically. Not only does having high hydrodynamic stability increase course keeping ability, but it facilitates dynamic behavior control of robot regarding the disturbances like marine currents in the water. Roll dynamic instability would be an adverse phenomenon for underwater vehicles results in the deviation from the main path. After mentioning governing motion equations of vehicle, hydrodynamic moment acting on the body has been computed numerically using computational fluid dynamics. The robot is assumed to be a rigid body and the flow passing over it is considered steady and incompressible. Having extracted relationship between moment and flow angular velocity, the linear hydrodynamic coefficient needed for stability analysis is estimated. Using this damping coefficient, roll dynamic stability of the robot has been evaluated. To ensure the accuracy of numerical results, computations are compared with axisymmetric body designed and manufactured in Ship Hydrodynamic Department of David Taylor Research Center; Comparisons show firmly good agreement with experiments. Results reveal that roll dynamic stability of proposed hull shape with triangular cross-section is 10 times as great as that of conventional axisymmetric body with circular cross-section.

Review History:

Received: 03/11/2018
Revised: 02/01/2019
Accepted: 11/03/2019
Available Online: 25/03/2019

Keywords:

Autonomous underwater vehicle
Fish-like hull shape
Roll dynamic stability
Computational fluid dynamics
Hydrodynamic damping coefficient

1. INTRODUCTION

Much research in the field of Autonomous Underwater Vehicle (AUV) hull shape has focused on reducing drag force and eventually some axisymmetric body forms have been proposed [1-3]. However, these conventional forms have not always been appropriate for every task defined for AUV. For example, Alvarez et al. [4] presented a suitable body for AUVs moving near the free surface which was different from typical hull shapes. Furthermore, inspired by some sea creatures, several forms were introduced [5-6]. Apart from velocity, hydrodynamic stability of an AUV should be considered. Numerous studies have found Computational Fluid Dynamics (CFD) as an effective tool in order to compute hydrodynamic damping coefficients needed for stability analysis [7-12].

In the current study, after proving high straight-line stability [13], roll dynamic stability of a fish-like AUV has been analyzed using CFD. The vehicle is assumed as a rigid body undergoing a rotational flow to simulate the axial rotation test. Obtaining relationship between hydrodynamic roll moment and flow angular velocity, the hydrodynamic roll damping coefficient needed for stability analysis has been extracted and compared to typical axisymmetric bodies.

2. ZAYANDEH RUD AUTONOMOUS UNDERWATER VEHICLE

Appreciating Zayandeh Rud river, an important river passing through the historic city of Isfahan in central part of Iran, fish-like vehicle inspired by catfish is called Zayandeh Rud Autonomous Underwater Vehicle (ZRAUV) and shown in Fig. 1.

As illustrated in Fig. 1, the proposed hull shape in contrast with typical AUVs which have circular cross section, has triangular cross section with a flat bottom.

3. MATHEMATIC MODEL

Motion equation in roll direction can be obtained as Eq. (1) when the origin of the Cartesian coordinate system is positioned in the center of gravity of the vehicle.

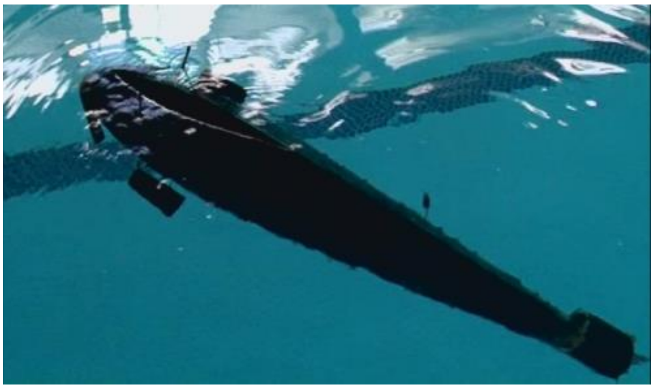

Fig. 1. Zayandeh Rud autonomous underwater vehicle

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$$\left(I_{xx} - K_{\dot{p}}\right)\dot{p} = K_p p + K_\phi \phi \qquad (1)$$

where I_{xx} denotes moment of inertia, $\dot{p}$ and p signify roll angular acceleration and velocity, respectively. ϕ is roll angle and $K_{\dot{p}}$ and K_p are hydrodynamic added mass and damping coefficients, respectively. In order to have the vehicle stable according to Routh-Hurwitz stability criterion the following requirement should be satisfied:

$$-K_p > 0 \qquad (2)$$

Afterwards, roll hydrodynamic damping coefficient is computed numerically using simulation of axial rotating test. In virtual test, the body is fixed undergoing rotational flow. As a consequence, having identified the relationship between roll hydrodynamic moment and its angular velocity K_p is estimated.

4. RESULTS

Fig. 2 displays numerical estimations for moment compared to experiments provided by Roddy [14]. Numerical results conform to experimental data in a reasonably good agreement.

Moreover, as depicted in Fig. 3, rotational flow around the ZRAUV during simulation of the axial rotation test, manifests

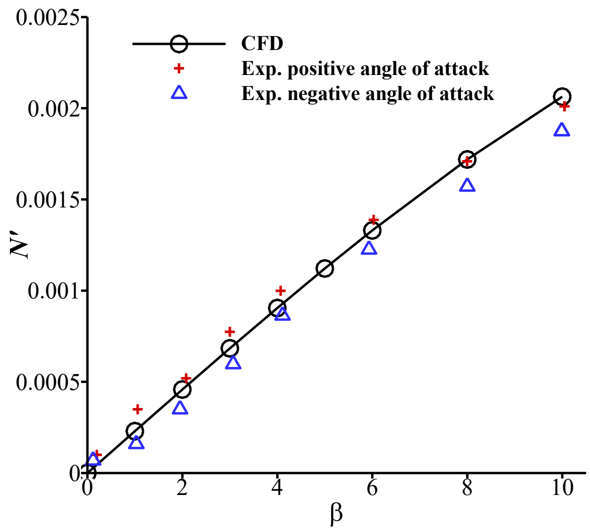

Fig. 2. Numerical results of moment in comparison with experiments for SUBOFF body

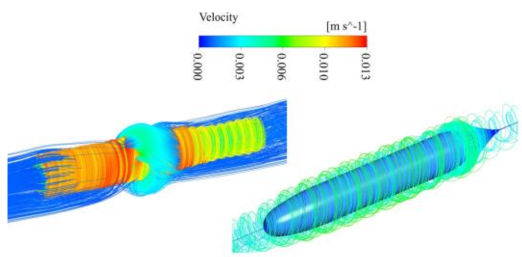

Fig. 3. Streamlines around SUBOFF (right) and ZRAUV (left) with angular velocity of 0.017 rad/s

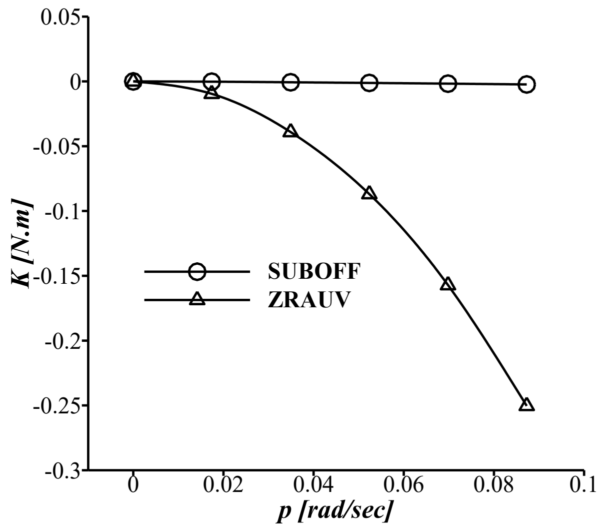

Fig. 4. Hydrodynamic moment around the longitudinal axis acting on ZRAUV and SUBOFF with respect to the angular velocity

separation phenomenon that might be the main reason for increasing hydrodynamic moment imposing on the body. On the other hand, fluid flow around SUBOFF as a conventional body does not show such a behavior. Finally, Fig. 4 describes how larger the roll moment acting on ZRAUV is than that of SUBBOF which causes greater roll damping coefficient.

5. CONCLUSIONS

Roll hydrodynamic stability for a fish-like autonomous underwater vehicle with a triangular cross section has been analyzed using computational fluid dynamics and compared with typical AUVs having circular cross section. Results revealed that the fluid flow properties such as pressure and velocity fields around ZRAUV in contrast to conventional AUV are completely asymmetric result in the high hydrodynamic damping moment. As a conclusion, having higher roll damping coefficient which is 10 times as great as that of typical AUVs, ZRAUV is more hydrodynamically stable.

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